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COMPRESSIVE STRENGTH OF DURALUMIN CHANNELS

Air Service Information Circular, Volume VI, No. 598

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Engineering Division
McCook Field
Dayton OH 45430

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COMPRESSIVE STRENGTH OF DURALUMIN CHANNELS

(AIRPLANE BRANCH REPORT)

▽

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COMPRESSIVE STRENGTH OF DURALUMIN CHANNELS

The purpose of this report is to record the results of tests of the compressive strength of duralumin channels, to recommend methods for their design, and to show the application of these methods to the design of channel-trussed beams.

All the specimens built and tested in the course of this investigation were of sheet duralumin, Air Corps Specification 11054, heat treated, to give the maximum physical properties. The subsequent discussion and the methods recommended for design purposes apply only to this kind of material.

It is apparent that the number of possible combinations of the lengths of the legs or sides of a channel with the width of back and gauge of material is very large. A channel is therefore nearly always designated by an expression in terms of the external dimensions of its cross section and the gauge of the material. These dimensions may be expressed either in feet or inches or in multiples of the gauge. For example, a 3 by 2 by 0.05 inch channel is a channel with a 3-inch back, 2-inch legs or sides, and 0.05-inch gauge material. In this case the expression in terms of the gauge t becomes $60t$ by $40t$ by t. The expressed dimensions of a channel are assumed to be outside dimensions unless otherwise stated. For the purposes of developing the methods of design and presenting them in a practical form, the term "standard channel" is used to designate any channel in which the ratio of the width of the back to the length of the legs or sides is equal to 2. Any channel other than a standard channel is considered in its relation to a standard channel with the same length of side and gauge of material.

CONCLUSIONS

Shape effect, as a controlling factor in limiting the ultimate compressive strength of a duralumin channel, is not a question of thickness of material, radius of bend, or extent of flat sheet, but is a function of the ratios of the dimensions of the cross section to the gauge of the material.

The ultimate compressive strength of a plain duralumin channel may be computed by means of the curves shown in Figures 8 and 9. The curves in Figure 8 give the maximum allowable unit stress in compression for standard duralumin channels which have a length of leg or side not less than twelve nor more than twenty-five times the gauge of the material. In Figure 9 is supplied a curve which gives a correction factor for channels other than standard ones. This curve is limited to channels in which the ratio of the width of back to length of leg is less than 6. The correction factor is applied to values obtained from the curves in Figure 8, as is explained more fully in the discussion of results.

The ultimate compressive strength of a duralumin channel in many cases may be increased over the values obtained from the curves in Figures 8 and 9 by stiffening the back or free edges to prevent or delay local failure. It may be done by one of the following methods which will be covered more fully in the subsequent discussion of results:

(*a*) One or more grooves or corrugations may be formed in the back of the channel, running parallel to the main axis of the member.

(*b*) A cover or reenforcing plate may be riveted to the back of the channel, extending parallel to the main axis of the member.

(*c*) Flanged lightening holes may be formed in the back of the channel.

(*d*) The free edges of the legs may be rolled or bent over.

(*e*) The free edges of the legs may be interconnected by means of bolts and spacers.

PROCEDURE

All channels built and tested in the course of this investigation were formed in a brake or by hammering with a wooden mallet over a hard wood block while the material was in the annealed condition. After the forming operations, the pieces were heat treated in a nitrate bath, being soaked at 925° F. for the time specified for the gauge of the material, and immediately quenched in boiling water for two hours. In all cases the material was bent to the radius specified in paragraph 18, page 308, of Section VII, Part II, of the April, 1925, edition of the "Handbook of Instructions for Airplane Designers." These radii are also shown in Table A-27, page 387, of "Airplane Design," by Alfred S. Niles, jr.

In the case of single channels to be tested in short lengths, the ends were squared up and made as nearly as possible parallel to each other and normal to the main axis of the member. Where the channels were designed for use in beams they were riveted together by means of duralumin rivets properly heat treated.

The short lengths of channels were tested in a 50,000-pound Olsen testing machine as shown in Figure 1. It will be noted that the ends of the specimens were supported in cradles. The cradles were mounted on knife edges that were at the same elevation as the ends of the test specimens. By this means, it was possible to test the channels as pin-ended columns with a column length that of the specimen and to obtain results that are believed to be very dependable. In a number of cases the physical properties of the material in tension were obtained from standard tensile test specimens cut from the channels after the compression tests.

A number of channel-trussed beams were also built and tested. In each case they were designed for the "Single-bay observation" loading given in McCook Field Serial Report No. 2450, entitled "Loadings for Experimental Airplane Spars". Both the chords and web members were of channel shapes, riveted together with lugs formed by extending portions of the sides of the chord channels. The jig in which these beams were tested is shown in Figures 2 and 3 as it was first installed. Later it was cut off at the lower end so as to rest on the weighing platform and was then installed on a 50,000-pound Olsen testing machine. The jig is so designed that the beam is loaded both axially and transversely, the side loads consisting of two concentrated loads applied at points 22.5 inches from the end supports. Each side load is maintained by the test jig at a constant ratio of 10 per cent of the end load. The length of the beams in each case was 96 inches center to center of pins at which the end load was applied and the side loads supported. Figure 3 shows a spruce beam in the test jig after failure of the beam in compression. It shows very clearly the method of supporting the beam and the application of the side loads.

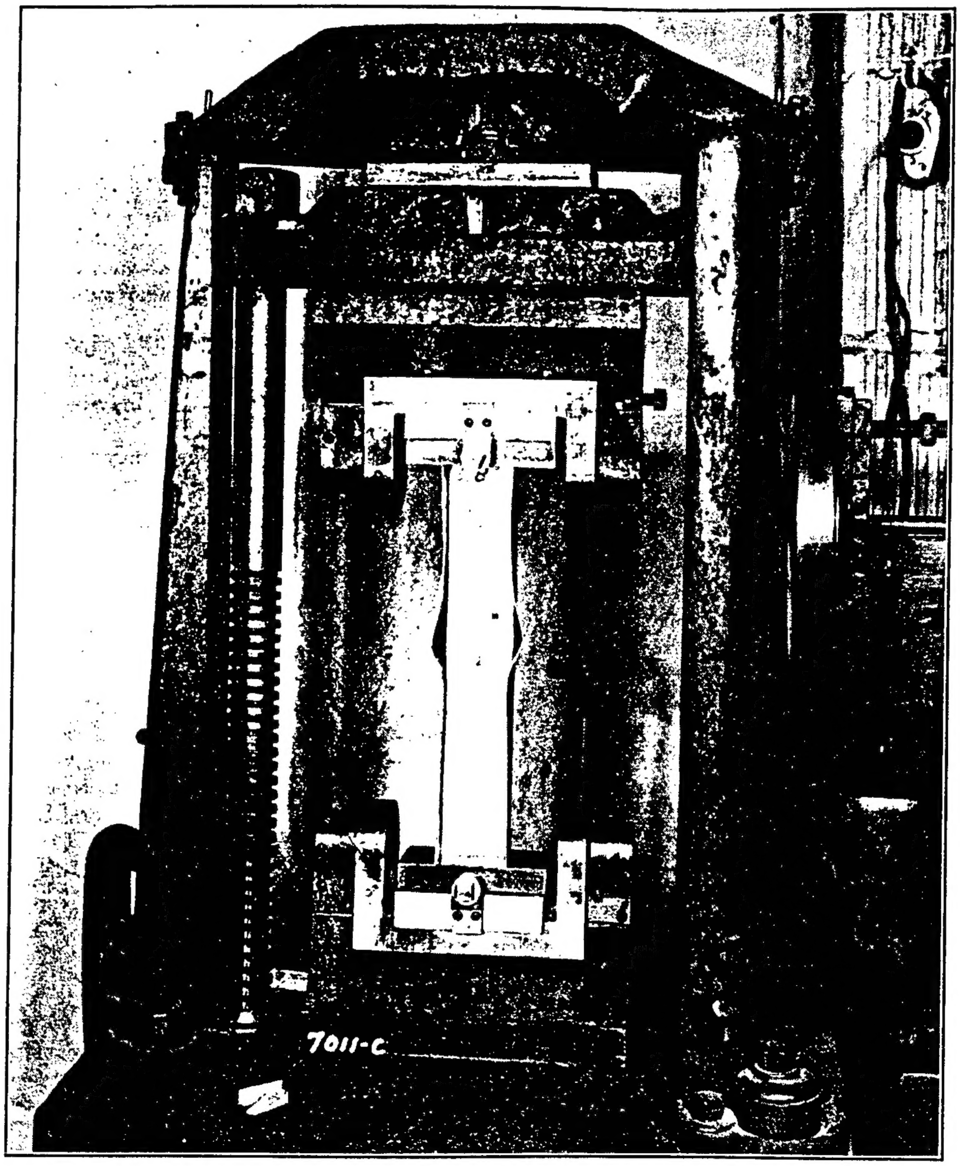


FIG. 1

Upon the completion of the tests of the beams under the standard "observation" loading, a number of tests of the minor parts of the beams were made. In the cases where the chord or web members had been stiffened in some manner to increase the ultimate strength over that to be expected from a plain channel, short lengths were cut from the beams, the ends squared up, and tested in the jig shown in Figure 1. Tests of the physical properties of the chord material in tension were also conducted.

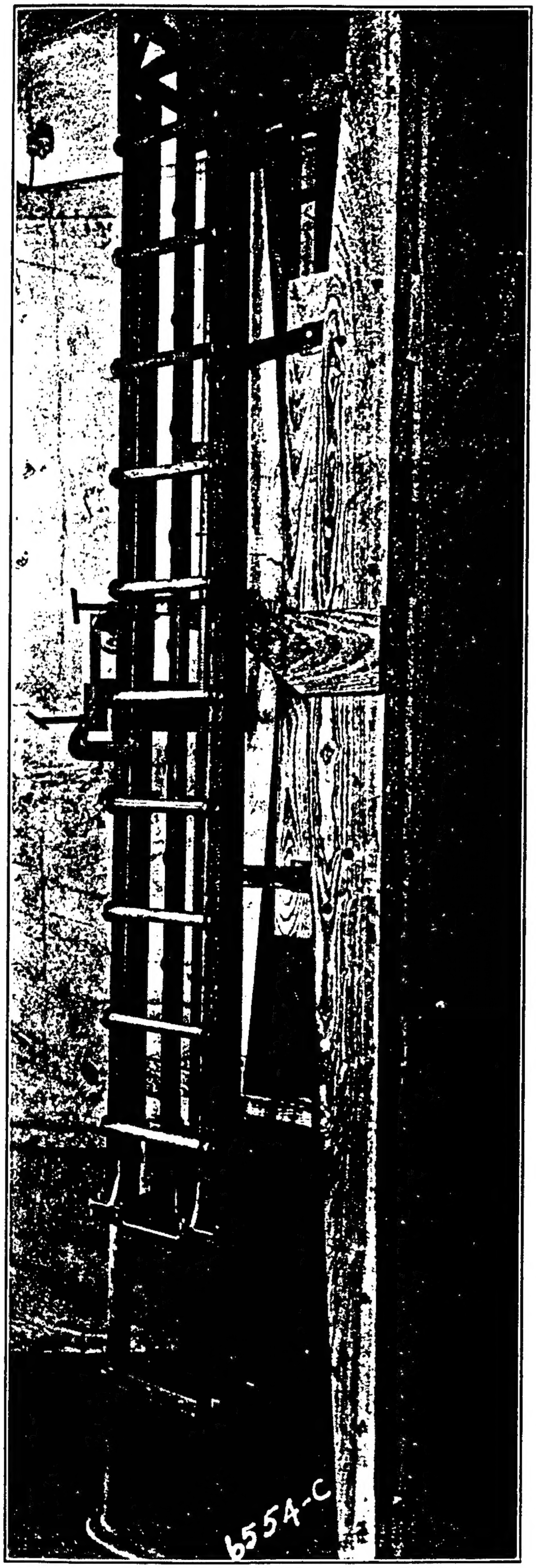


Fig. 2

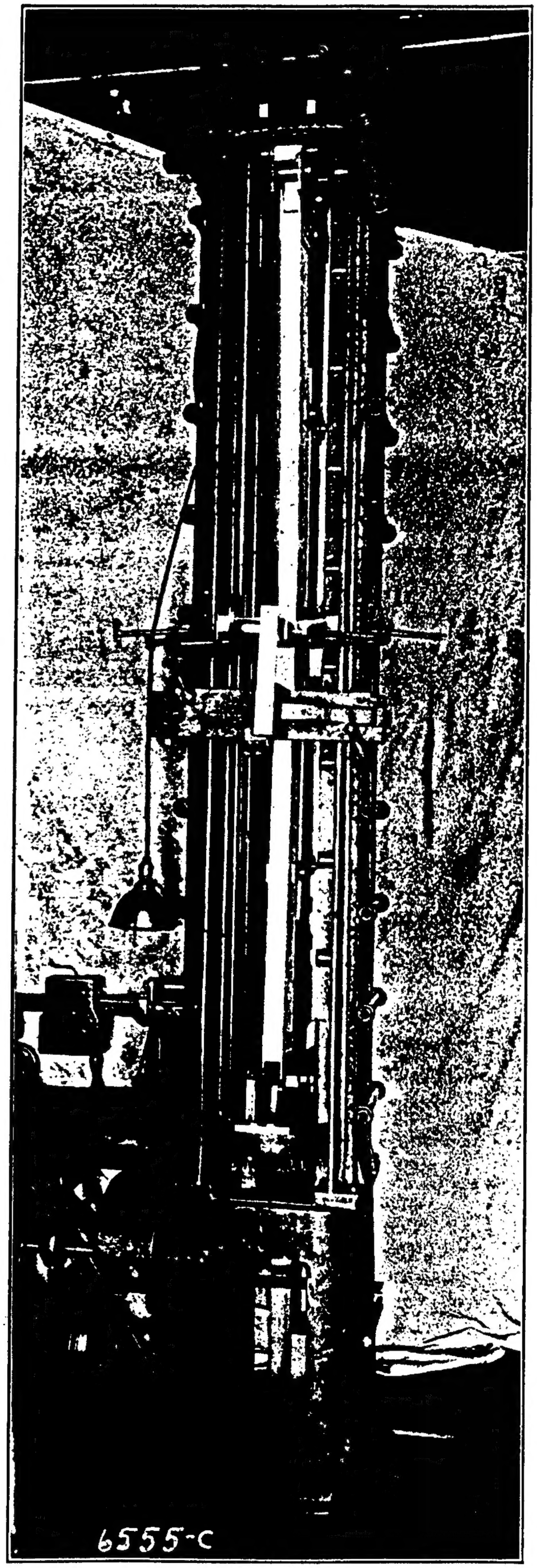


Fig. 3

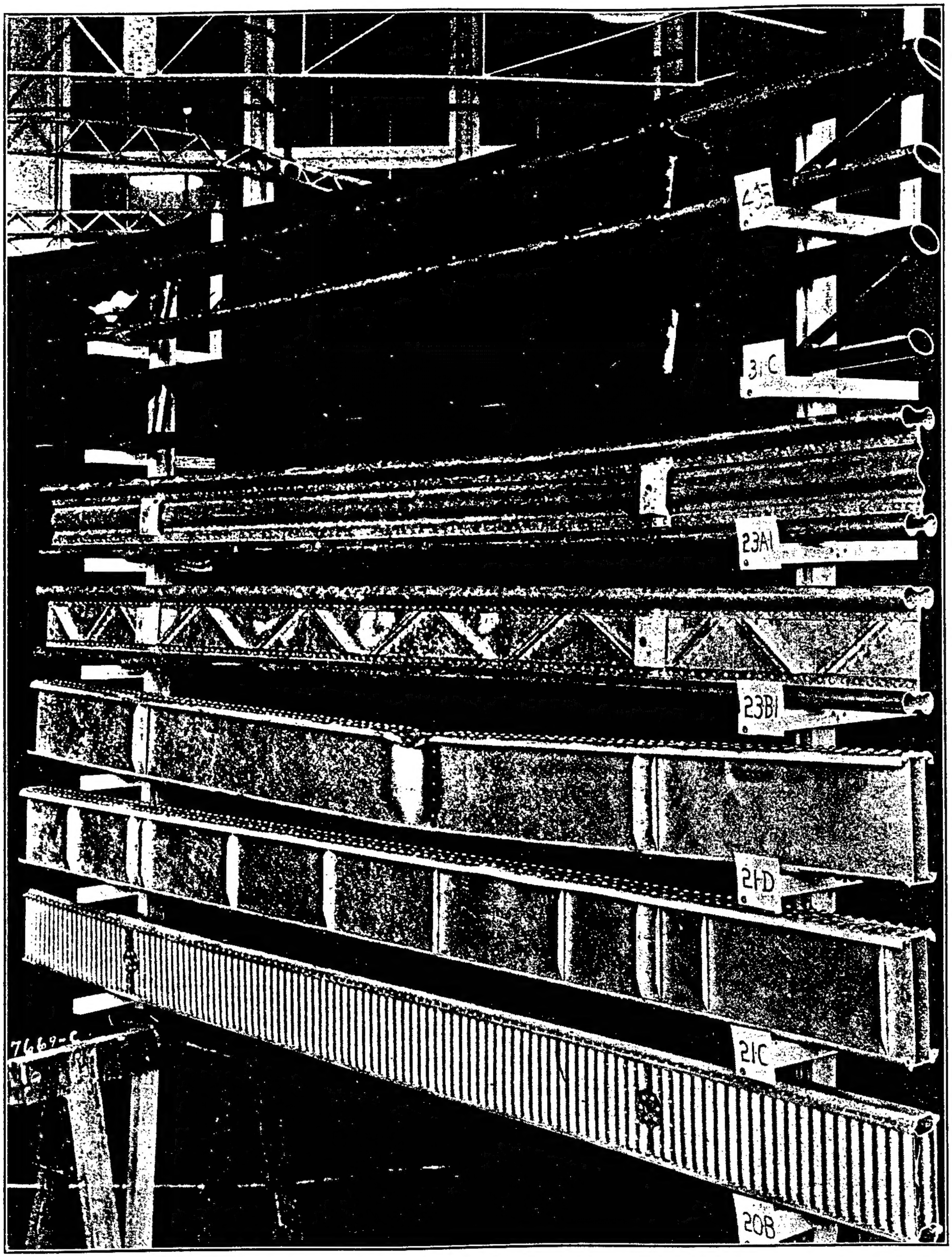


FIG. 4

DISCUSSION OF RESULTS

Plain channels

If a thin flat sheet of duralumin were tested as a column by the application of axial compression loads at the edges, it would fail or buckle at a comparatively small unit stress as its radius of gyration would be extremely small, being equal to 0.2887 times the gauge. For example, take a sheet of 0.049 material, with a width of 4.56 inches and a length of 10 inches. Considering this sheet as a column, it would have an area of 0.2234 square inch a least moment of inertia of 0.00004471, and a computed column strength of 44 pounds by Euler's formula for pin-ended columns. If, however, we assume this same sheet of material to be rolled in the form of a tube of the same gauge and length and with an outside diameter of 1.50 inches, it would have a computed ultimate strength as a pin-ended column in compression of 8,760 pounds.

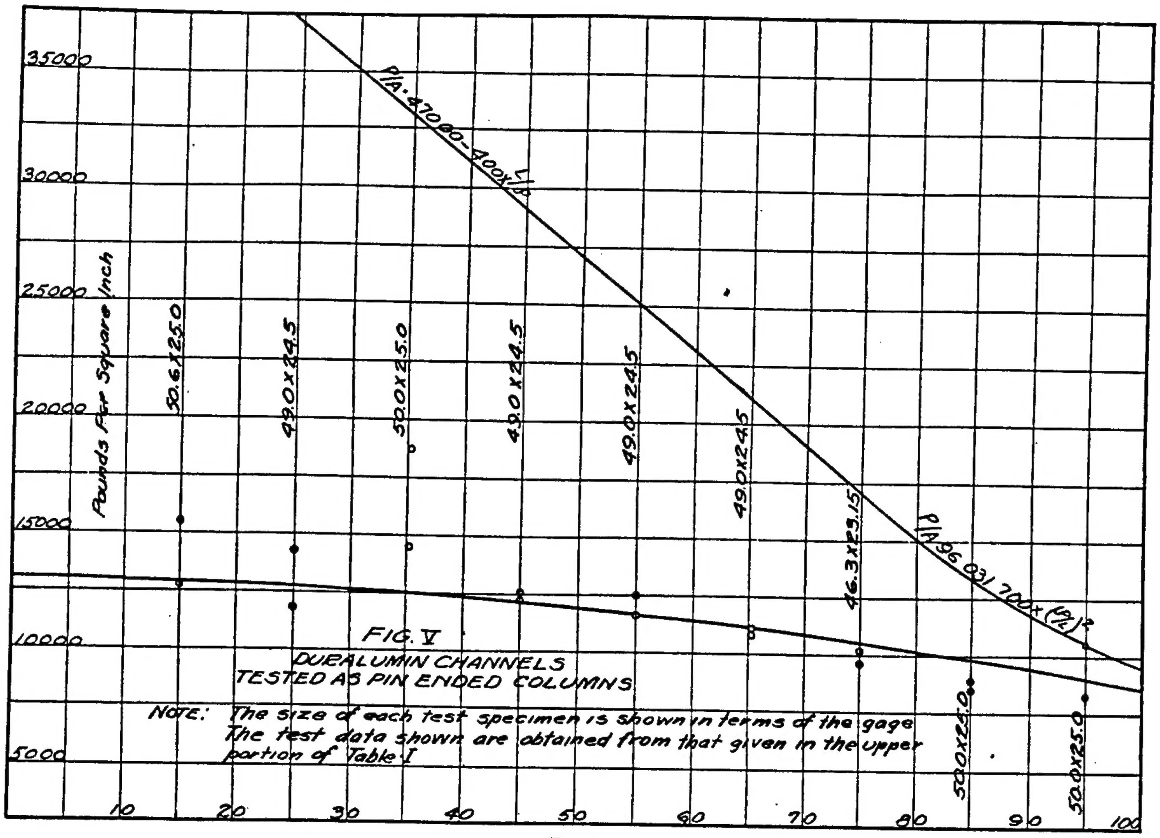
Consider a longitudinal element of the above tube as it sustains an axial compression load. As the load reaches the Euler strength of the element, the element tends to fail by bending, the bending being along the radial line passing through the element. As all the elements of the tube are similarly stressed, they all tend to fail along radial lines, but their failure is greatly delayed by circumferential forces, which may be either tension or compression and which unite the elements in their action so that the tube fails at its ultimate strength rather than at that of a longitudinal element. There is no such result in the case of a flat sheet as each logitudinal element tends to fail by bending in a direction normal to the sheet and the Euler strength of the sheet as a column is at the same unit stress as the Euler strength of any longitudinal element. If, however, the diameter of the tube were greatly increased while the gauge is decreased, the longitudinal element would approach the case of the flat sheet and the tube would fail in axial compression at a comparatively small load, though its computed strength might be rather large. For want of a better name the phenomenon is called "shape effect" and the type of failure designated as "local" or "crinkling".

In the case of a plain channel we have the flat sheet broken up into three flat surfaces by means of two 90° bends in the sheet. The longitudinal elements under axial compression loads tend to act as in the case of the flat sheet, but failure is delayed as each of the flat surfaces receives support along its edges from one or more of the others. It is apparent that the sides are comparatively strong in bending in a direction normal to the surface of the back, the direction in which the back is weakest. The back is strongest in bending in the direction in which the sides are most weak. As this mutual support among the three flat surfaces forming the channel can only be due to bending in a plane normal to the longitudinal axis of the column, the back portion of the cross section acts as a beam supported and more or less fixed at each end, and each side or leg acts as a cantilever beam more or less fixed at its point of support. It seemed, then, that shape effect in the case of a channel would depend both on the ratio of the width of the back to the gauge of the material and the ratio of the width of side to the gauge. The most efficient channel—i. e., a channel where failure is as apt to occur in the back as at the free edges of the sides would probably be one in which the width of the back is equal approximately to twice the width of the sides. For the purposes of this report, a channel so proportioned that the width of the back is twice the width of the sides is designated as a "standard" channel and all other channels are considered in their relation to some standard channel of the same width of side and gauge of material.

In the course of this part of the investigation 102 channels were built and tested. The sizes of the channels, properties of the cross sections, and loads at failure are shown in Tables 1, 2, and 3. The test specimens are practically all of 0.05 material, one series being run of 0.0625 material to serve as a check. In each main series a different sized standard channel was tested with varying values of the slenderness ratio. For each main series a second series was tested with constant values of the slenderness ratio and the ratio of the width of side to the gauge, and with varying ratios of the width of back to the gauge. All specimens were tested as pin-ended columns, the test set up being shown in Figure 1. A typical channel failure is also shown in Figure 1, the outward failure of the sides being accompanied by a failure of the back in the direction of the free edges. As indicated in the tables, an effort was made in most cases to note whether the sides or the back failed first. The results, however, are rather inconsistent, as in thin gauge channels the failure is so sudden and complete that in most cases it is largely a matter of opinion as to whether the sides or the back failed first. Great care was exercised in conducting the tests to make sure that the axial load would be applied along the neutral plane of the specimen. As the load was applied, transverse deflection readings were noted, though not included in this report. If these readings indicated that the load was so applied as to cause an eccentricity, the test was stopped and the specimen shifted slightly in the jig by means of the micrometer adjusting screws.

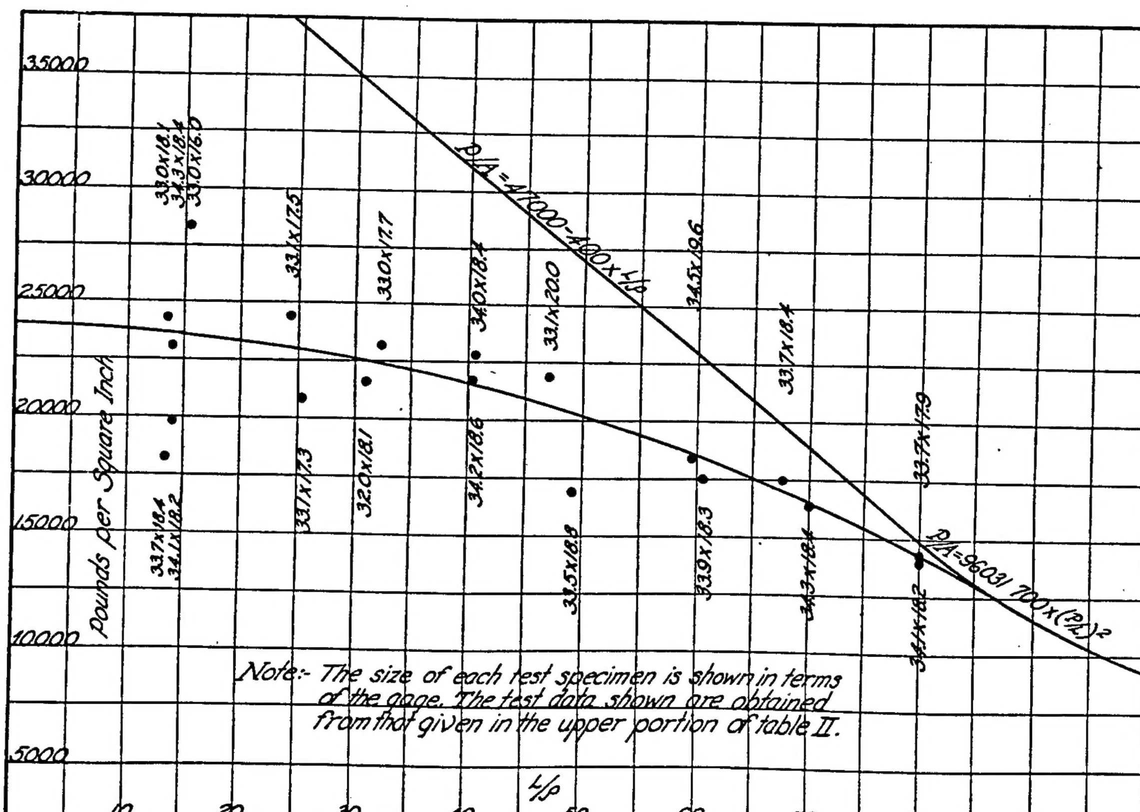
The results of the tests in the three series of standard channels are plotted in Figures 5, 6, and 7. It will be noted from the sizes shown in Figures 6 and 7 that these specimens are only approximate standard channels. The data in these figures show, however, that as the dimensions in terms of the gauge decrease, the allowable stress intensity increases for all values of the slenderness ratio short of the Euler range. It was thought that Johnson's parabolic formula with appropriate values of the yield point together with Euler's formula fitted the results very well. The scope of these tests was not great enough to cover the Euler range, but in each series, especially the two plotted in Figures 5 and 6, the tendency of the points is to converge on the Euler curve as the higher values of the slenderness ratio are reached. It seemed safe, then, to assume that channel struts, as other forms of struts, will follow the Euler curve in the range of the smaller maximum allowable stress intensities. These formulas are also shown in Figures 5, 6, and 7.

It will be noted that the results are less consistent for the shorter values of the slenderness ratio, due undoubtedly to slight irregularities in the free edges



35000
30000
25000
20000
15000
10000
5000
Pounds Per Square Inch
P/A=47000-400×L/ρ
P/A=96 031 700×(ρ/L)²
50.6×25.0
49.0×24.5
50.0×25.0
49.0×24.5
49.0×24.5
49.0×24.5
46.3×23.15
50.0×25.0
50.0×25.0
FIG. V
DURALUMIN CHANNELS
TESTED AS PIN ENDED COLUMNS
NOTE: The size of each test specimen is shown in terms of the gage
The test data shown are obtained from that given in the upper
portion of Table I
10
20
30
40
50
60
70
80
90
100

FIG. 5



35000
30000
25000
20000
15000
10000
5000
Pounds per Square Inch
P/A=47000-400×L/ρ
P/A=96031 700×(ρ/L)²
33.0×18.1
34.3×18.4
33.0×16.0
33.1×17.5
33.0×17.7
34.0×18.4
33.1×20.0
34.5×19.6
33.7×18.4
33.7×17.9
33.7×18.4
34.1×18.2
33.1×17.3
32.0×18.1
34.2×18.6
33.5×18.8
33.9×18.3
34.3×18.4
34.1×18.2
Note:- The size of each test specimen is shown in terms
of the gage. The test data shown are obtained
from that given in the upper portion of table II.
L/ρ
10
20
30
40
50
60
70
80
90
100

FIG. 6

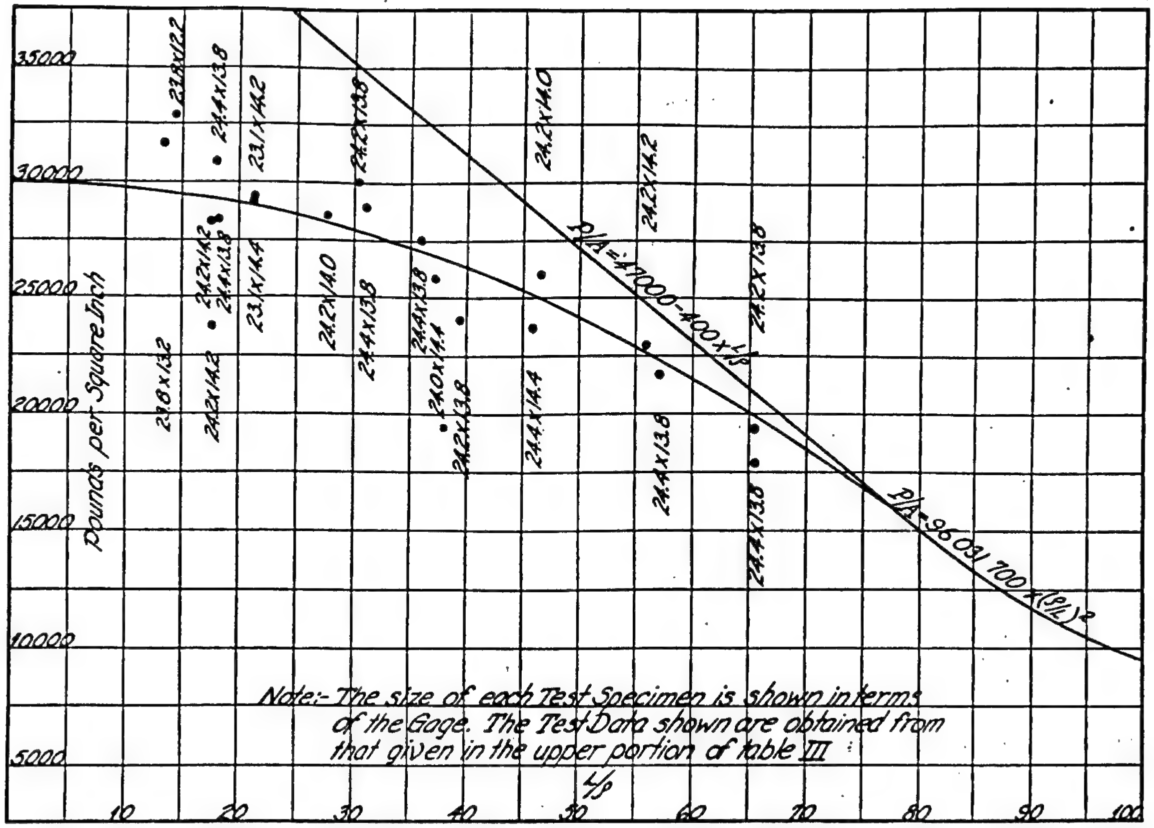

35000
30000
25000
20000
15000
10000
5000
Pounds per Square Inch
P/A = 47000-400 x L/ρ
P/A = 96031700 x (ρ/L)²
Note:- The size of each Test Specimen is shown in terms of the Gage. The Test Data shown are obtained from that given in the upper portion of table III
L/ρ
10
20
30
40
50
60
70
80
90
100

FIG. 7

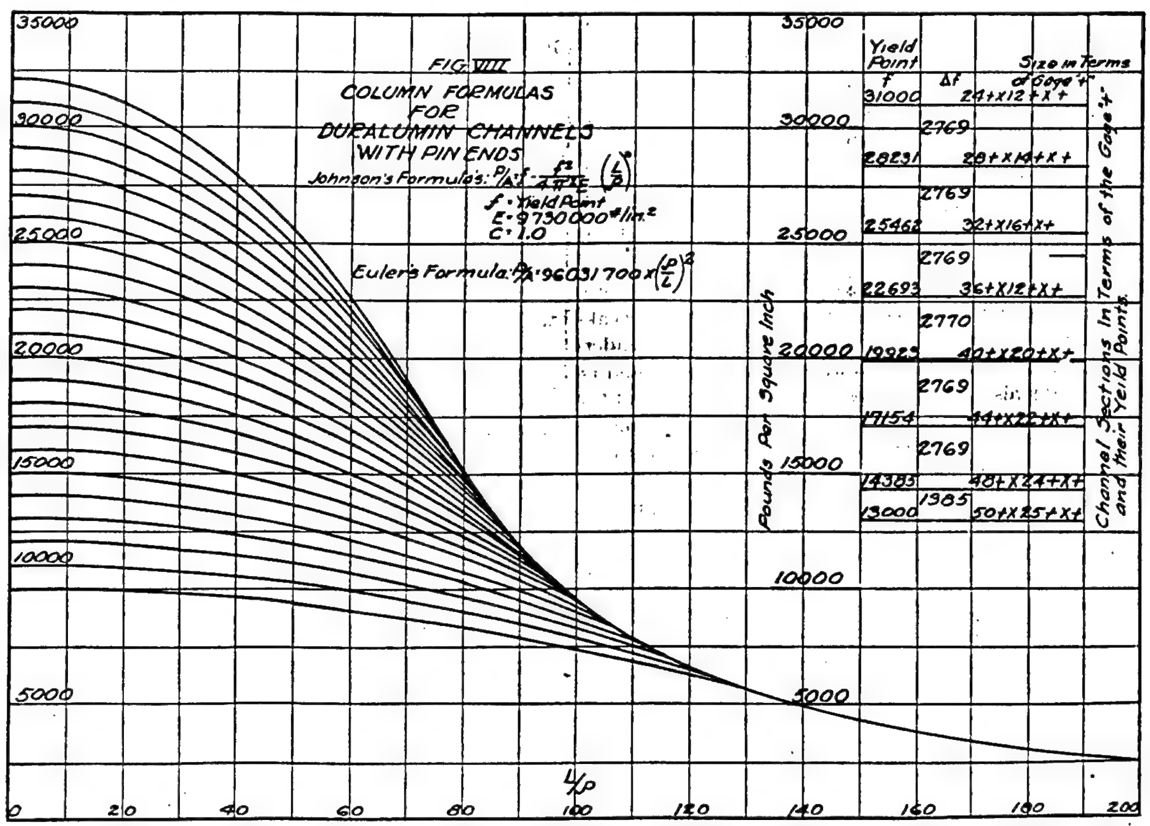


FIG. VIII
COLUMN FORMULAS FOR DURALUMIN CHANNELS WITH PIN ENDS
Johnson's Formula: P/A = f - f²/(4π²E) (L/ρ)²
f = Yield Point
E = 9730000#/in.²
C = 1.0
Euler's Formula: P/A = 96031700 x (ρ/L)²
Yield Point f
Δf
Size in Terms of Gage "t"
31000
24t x 12t x t
2769
28231
28t x 14t x t
2769
25462
32t x 16t x t
2769
22693
36t x 12t x t
2770
19923
40t x 20t x t
2769
17154
44t x 22t x t
2769
14385
48t x 24t x t
1385
13000
50t x 25t x t
Channel Sections in Terms of the Gage "t" and their Yield Points
Pounds Per Square Inch
35000
30000
25000
20000
15000
10000
5000
L/ρ
0
20
40
60
80
100
120
140
160
180
200

FIG. 8

of the channels which would have a greater effect at the higher stress intensities.

Allowances were made for the fact that the channels plotted in Figures 6 and 7 varied somewhat from standard shapes and the three Johnson parabolic curves together with the Euler curve for duralumin were plotted in Figure 8. It was found that the yield points for the three curves, in terms of the side-gauge ratio of the channels, varied almost in a straight line. So a series of yield points was obtained for various sized channels, in each case the size of the channel being in terms of the gauge and the channel being a standard channel as shown. The assumption that the yield points of standard channels vary as a straight line in terms of the side-gauge ratio is not in serious error for the range of this investigation. It is believed that it would be satisfactory to continue this straight line to include channels with side-gauge ratios less than 12, but that to extend it to include channels with side-gauge ratios greater than 25 will tend to results that are unnecessarily conservative. The following case will serve as an example of the use of the design chart, Figure 8.

Assume a duralumin channel 1¼ by ⅝ by 0.05 inch. In terms of the gauge t the size is $25t$ by $12.5t$ by t. From the table on the right of the design chart, Figure 8, we find the yield point is $31{,}000-0.25\times2{,}769=30{,}308$ pounds per square inch. If the inside radius of bend in forming this channel is one-sixteenth inch, the area of the cross section is 0.1162 inch, the least moment of inertia is 0.004415 and least radius of gyration is 0.1949. If the length is assumed as 10 inches, the slenderness ratio is 51.3. Assuming the ends are round—i. e., $c=1$, the allowable stress intensity of this channel strut in compression=

$$P/A=30{,}308-\frac{30{,}308^2}{4\times\pi^2\times9{,}730{,}000}\times51.3^2=24{,}013\#/\square''$$

The value of the allowable unit stress, once the yield point and the slenderness ratio were known, could have been obtained directly from the design chart, Figure 8, by interpolation.

It seemed reasonable to believe that if the back of a given channel be increased in width, it would be weakened somewhat and that for a given value of the slenderness ratio the maximum allowable unit stress would be decreased; also it seemed reasonable to believe that the combined Johnson parabolic and Euler curves could be used for odd-shaped channels as well as standard ones if the yield point for use in the parabolic portion of the curve were known. It was decided then to plot the data obtained from the tests of odd-shaped channels in terms of yield points and ratios of the width of the back to the width of the sides, the use of yield points being favored as it eliminated errors due to variations in the value of the slenderness ratios of the specimens being considered. The available data are shown in Figure 9, the abscissas being in terms of the ratio of the width of back to the width of sides and the ordinates being in terms of the ratio of the yield point of the specimen plotted to the yield point of a standard channel that has the same width of leg and gauge of material. In any case the yield point of the channel in question was obtained by plotting it in Figure 8 and drawing a parabolic curve through the point and extending the curve to the origin. The yield point of the standard channel to be used in obtaining the yield point ratio was obtained from Figure 8.

It will be noted that the points in Figure 9 do not show a well-defined curve but do show a tendency to form a band. Any curve that might be drawn must of necessity pass through the point that has a yield point ratio of 1 and a back-side ratio of 2. The straight line shown in Figure 9 seemed to follow a general average of the points, and it was decided to use it until a more general investigation should show the advisability of modifying it. The following case will serve as an example of the use of the design charts, Figures 8 and 9.

Assume a duralumin channel 2½ by ⅞ by 0.05 inch. In terms of the gauge t the size is $50t$ by $17.5t$ by t. The ratio of the back to the side is 2.857 and the yield point ratio is equal to $1.267-0.13337\times2.857=0.886$. (The yield point ratio can be read directly from the chart.) From Figure 8 we find that a standard channel whose size is $35t$ by $17.5t$ by t has a yield point of $22{,}693+0.25\times2{,}769=23{,}385$ pounds per square inch. Then the yield point for the 2½ by ⅞ by 0.05 inch channel is equal to $23{,}385\times0.886=20{,}719$ pounds per square inch. If the inside radius of bend in forming this channel is one-sixteenth inch, the area of the cross section is 0.2037 square inch, the least moment of inertia is 0.01408 and the least radius of gyration is 0.2629. If the length is assumed to be 10 inches, the slenderness ratio is 38.04. Assuming the ends to be round, the allowable stress intensity for this channel may be read directly from the chart, Figure 8, by interpolation or it may be computed as follows:

$$P/A=20{,}719-\frac{20{,}719^2}{4\times\pi^2\times9{,}730{,}000}\times38.04^2=19{,}102\#/\square''.$$

It should be noted that in this case or in the previous one for the design of a standard channel, if the slenderness ratio had been sufficiently large—120, for example—the strut would have been an Euler strut and its allowable maximum unit stress or its ultimate strength would have been obtained directly by Euler's formula without any correction for shape effect.

It is believed that the design charts, Figures 8 and 9, can be used with confidence for the design of duralumin channels. The scope of the tests is not as wide as could be desired, but the proposed curves, especially for the higher values of the yield point are a little conservative for the data that have been obtained. As was noted, practically all the test specimens were of 0.05 material, though one series was run of 0.0625 material as a check. However, a number of channel trussed beams were built and tested which will be discussed in subsequent paragraphs, and the results of the tests of these beams has checked the design charts in a very satisfactory manner. The beams in question were of 0.125 material.

It will be noted in the two examples of the use of the design charts that the radius of curvature of the bends in forming the channels was considered in the computations. It is important that the effect of the bends made in forming the channels be considered in all strength calculations for channels, as their neglect is

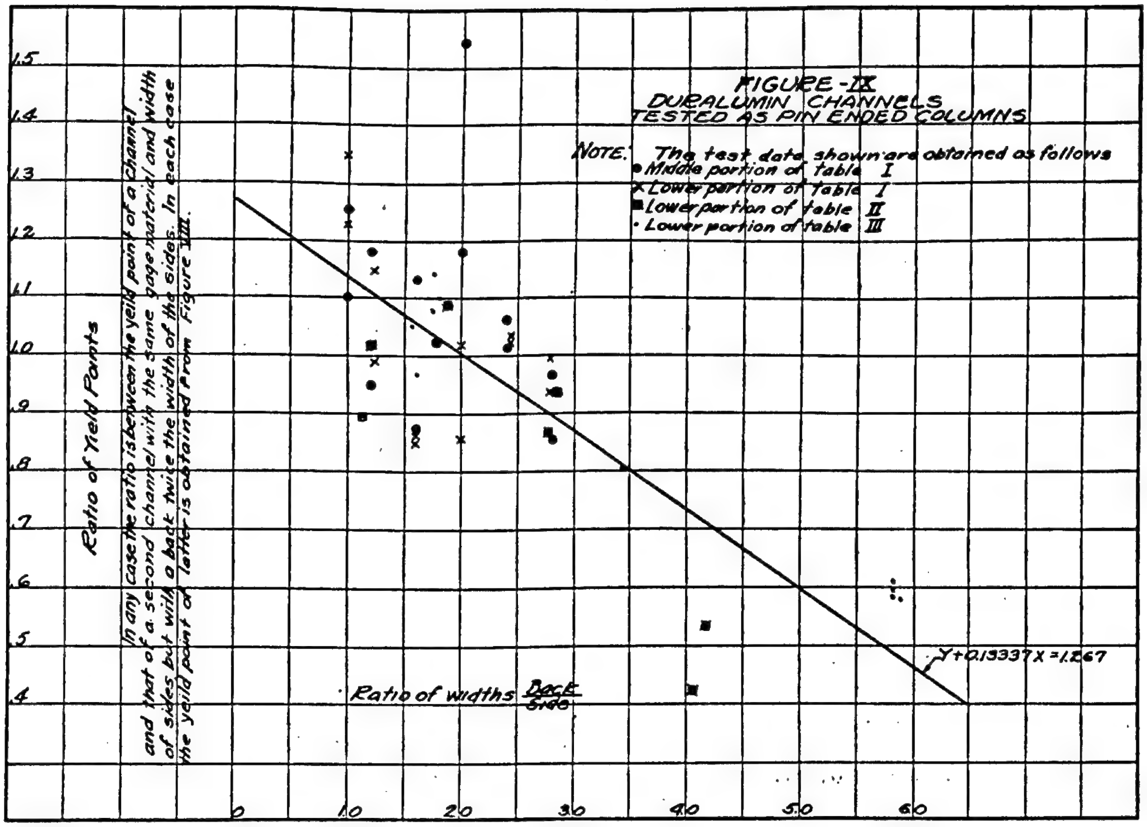


FIGURE - IX
DURALUMIN CHANNELS
TESTED AS PIN ENDED COLUMNS
NOTE: The test data shown are obtained as follows
• Middle portion of table I
x Lower portion of table I
■ Lower portion of table II
· Lower portion of table III
Ratio of Yield Points
In any case the ratio is between the yeild point of a channel and that of a second channel with the same gage material and width of sides but with a back twice the width of the sides. In each case the yeild point of latter is obtained from Figure VIII.
Ratio of widths Back/Side
Y+0.13337X=1.267
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
0
1.0
2.0
3.0
4.0
5.0
6.0

FIG. 9

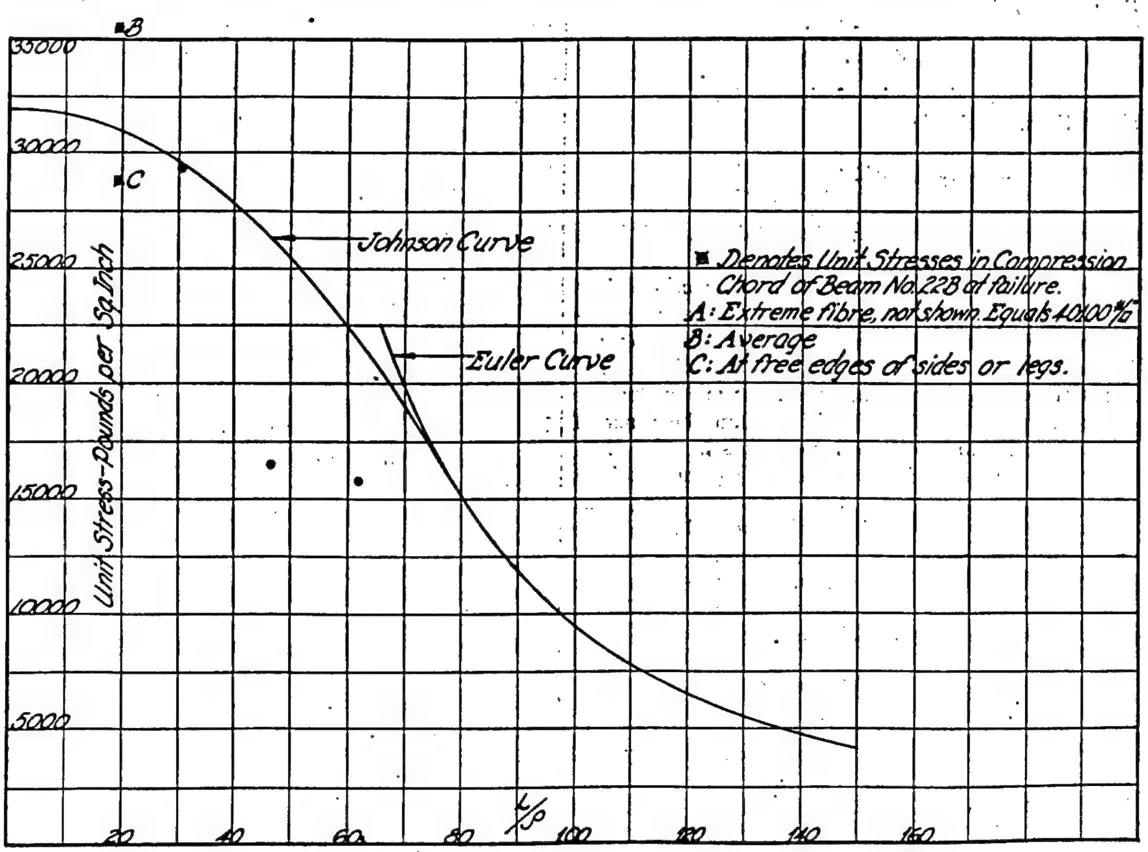

B
C
Johnson Curve
Euler Curve
■ Denotes Unit Stresses in Compression Chord of Beam No. 22B at failure.
A: Extreme fibre, not shown. Equals 40,100 #/□"
B: Average
C: At free edges of sides or legs.
Unit Stress-Pounds per Sq. Inch
L/ρ
35000
30000
25000
20000
15000
10000
5000
20
40
60
80
100
120
140
160

FIG. 10

generally on the unsafe side. The error is small for gauges so thin that the material may be bent with a radius of one-sixteenth inch, but for the thick gauges which may require a radius of bend of three-eighths inch or more, the error is more serious. In the case of the example for the design of a standard channel, the allowable end load is 24013×0.1162=2,790 pounds. If the bends had been neglected and the corners assumed to be square, the area would have been 0.1200 square inch, the least moment of inertia 0.004522, the least radius of gyration 0.1940, the slenderness ratio 51.55, and the maximum allowable unit stress 23954 pounds per square inch. The allowable end load would be 23954×0.12=2874.5 pounds, an increase on the unsafe side of 3.03 per cent. In the case of a 3.30 by 1.27 by 0.127 inch channel with a radius of bend of 0.25 inch the error due to the neglect of the curvature at the corners was 4.96 per cent and in the case of a 2.92 by 1.39 by 0.156 inch channel with a radius of bend of 0.40 inch, 8.18 per cent, the error in both cases being on the unsafe side.

In taking account of the bends in the duralumin in forming channels, the following formulas for a semicircular tube section of inside radius r_2 and outside radius r_1 are very useful. $r_1-r_2=t$, the gauge of the material. r_2 is the radius of bend for duralumin specified by the Air Corps.

$$\text{Area}=\frac{\pi}{8}\times(r_1^2-r_2^2)$$

The distance, x, from the base of the semicircle to the neutral axis

$$=\frac{4}{3\pi}\times\frac{r_1^3-r_2^3}{r_1^2-r_2^2}.$$

The moment of inertia of the semicircular section about the neutral axis

$$=\frac{\pi}{8}\times(r_1^4-r_2^4)-\frac{8}{9\pi}\times\left(\frac{r_1^3-r_2^3}{r_1^2-r_2^2}\right)^2$$

The computations necessary to obtain X and I are rather tedious, especially when accurate values are desired. However, it was noticed in computations for channels that practically all the error in the allowable end load was in every case due to the difference in the areas obtained. The difference in the radii of gyration obtained by the approximate and by precise methods was so small as to fall within the range of slide rule error and was always on the safe side. It is believed, then, that the work can be lessened without sacrificing accuracy if, for the purpose of computing the value of the radius of gyration of a channel, the bends at the corners be assumed square. The correct value of the area, however, should be used with the allowable maximum unit stress in order to obtain the allowable end load for the channel.

Stiffened Channels

A number of duralumin channels whose backs or sides had been stiffened or reenforced to delay local failure were built and tested to failure in compression. The results of these tests are to be found in Table 4 and Figures 10 to 14, inclusive. These channels were tested as pin-ended columns, the jig shown in Figure 1 being used. Both in the table and in the figures, the stiffened channels are compared with plain ones of the same size and gauge, in the table by means of yield points and strength volume ratios and in the figures by means of a column curve for the plain section. In the column headed "Yield Point for P/A at Failure" is shown for each specimen the value of f in the Johnson curve that, with the slenderness ratio of the specimen, would give the same value of P/A that was obtained in the test of the specimen. Under the heading "Plain Channel of Same Dimensions" are given for each test specimen the yield point f and computed end load P for a channel of the same dimensions but without stiffening, these values being obtained from the design charts in Figures 8 and 9. An average value of f for each group was used to obtain the Johnson curve plotted in the figures. When the dimensions of a test specimen were such that it fell outside the range covered by the design charts, it was assumed that the yield points varied in the same straight line that was assumed in arranging the charts. The ratios of end load to volume are a measure of the efficiency of the method of stiffening when applied to a strut. In computing the volumes of the channels with flanged lightening holes, only the material cut out in forming the hole was deducted. It is apparent that the ratios of channels of different size and length are not directly comparable.

These channels are not a part of an arranged series of test specimens but were salvaged from channel-trussed beams after the beams had been tested to failure by combined axial and transverse loads. As a result the range of this part of the investigation is not thoroughly covered and the results are not as well defined as could be desired. The specimens with flanged lightening holes were used as web members in the beams and the others of ⅛-inch gauge had served as chord members. In salvaging these test specimens from the beams an effort was made to use only those portions that had not been severely stressed in the beam test. Nevertheless, the lack of consistency of the results in some cases may be due in part to the loads the material had previously been subjected to. In the case of specimens 22B 2 and 3, the low values of the unit stress at failure are undoubtedly due to the presence of unfilled rivet holes in the sides of the channels. It is to be regretted that these tests do not cover a sufficiently wide range in a manner to enable a method of design and the efficient use of these methods of stiffening to be determined. It is hoped, however, that these data will be of assistance in arranging future tests to clarify this phase of channel design and that in the meantime they may serve as a guide for the design of similar members.

The backs of the channels in the 22B series are stiffened by means of a strip of duralumin 0.9 by 0.125 inch riveted along it. The rivets are spaced at about 1½ inches. This method of stiffening the back of a channel is similar to that of using cover plates on the flanges of a plate girder. It is effective in that the material used for stiffening is also carrying its proportion of the load and, in the case of wing spars

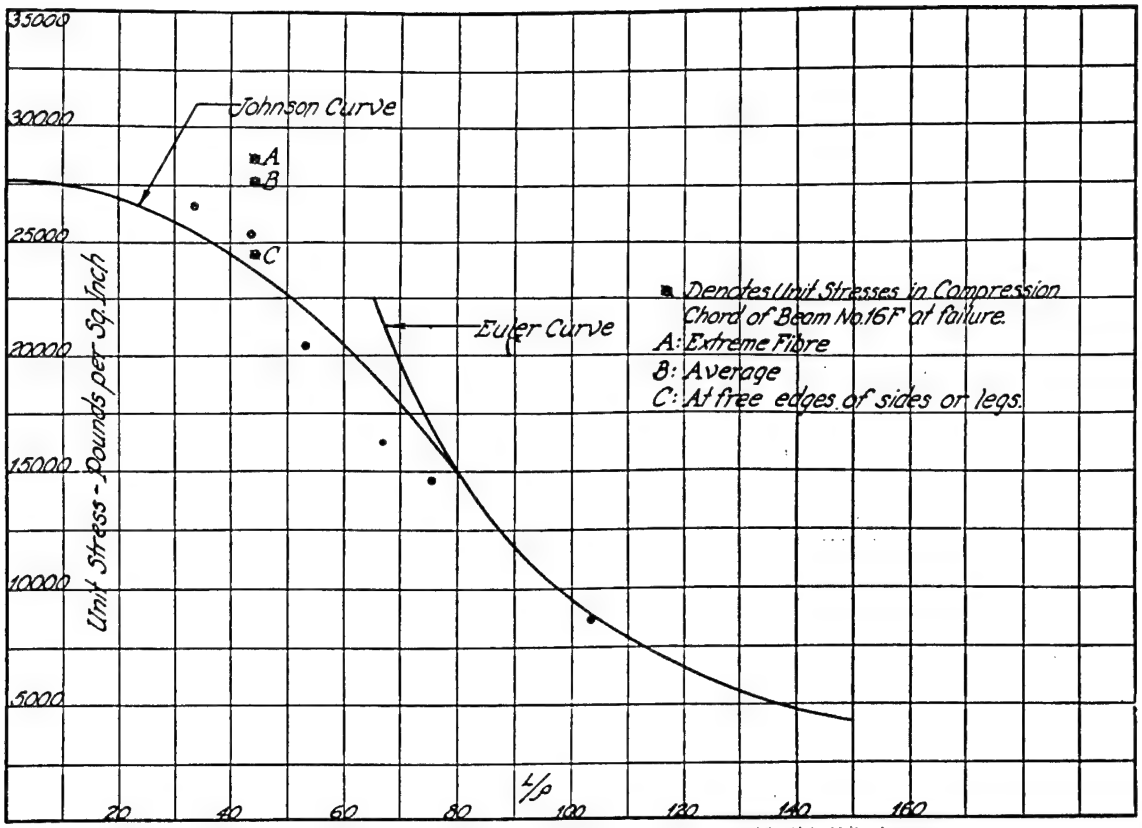

Johnson Curve
A
B
C
Euler Curve
Denotes Unit Stresses in Compression Chord of Beam No.16F at failure.
A: Extreme Fibre
B: Average
C: At free edges of sides or legs.
Unit Stress - Pounds per Sq. Inch
L/ρ
35000
30000
25000
20000
15000
10000
5000
20
40
60
80
100
120
140
160

FIG. 11

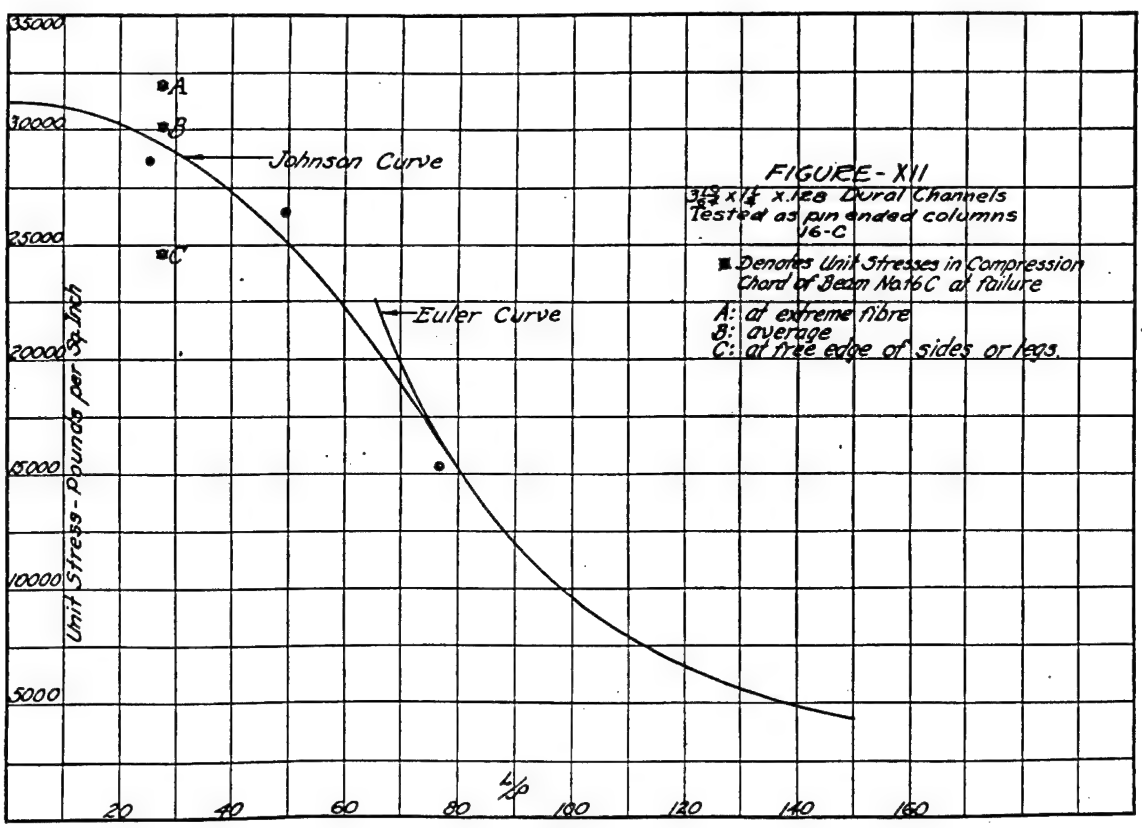
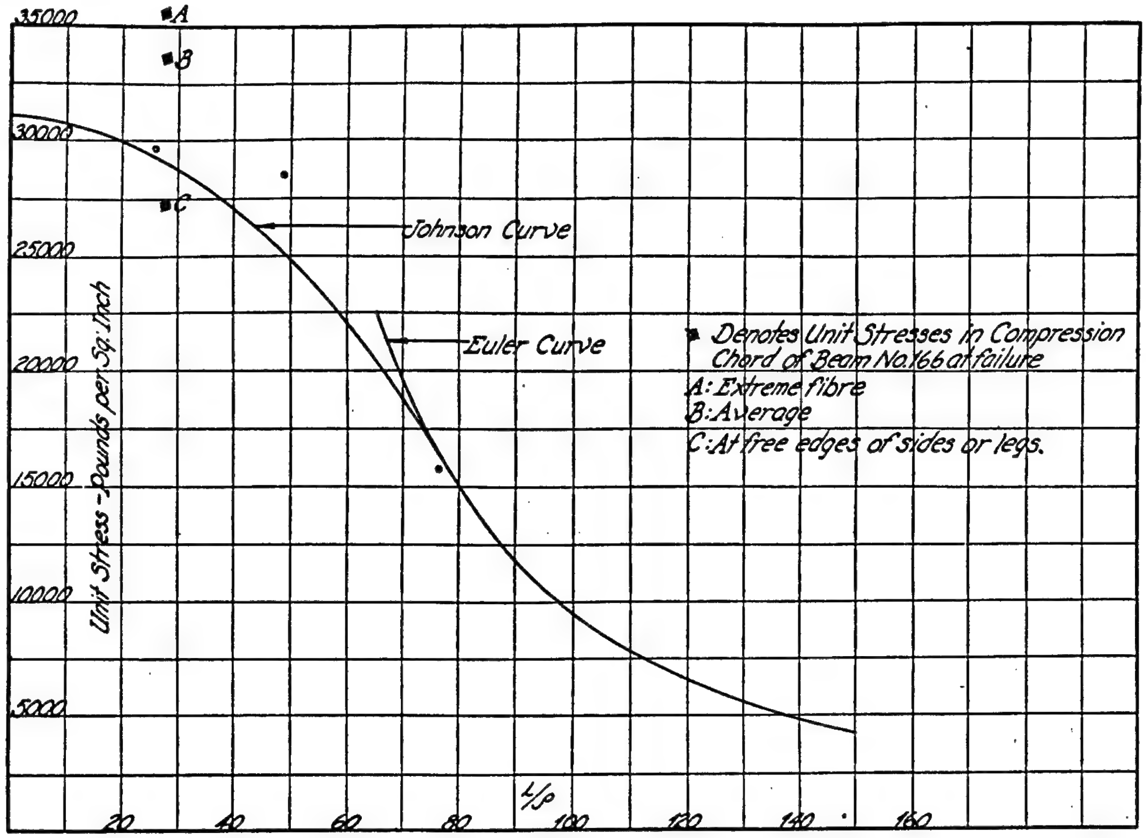
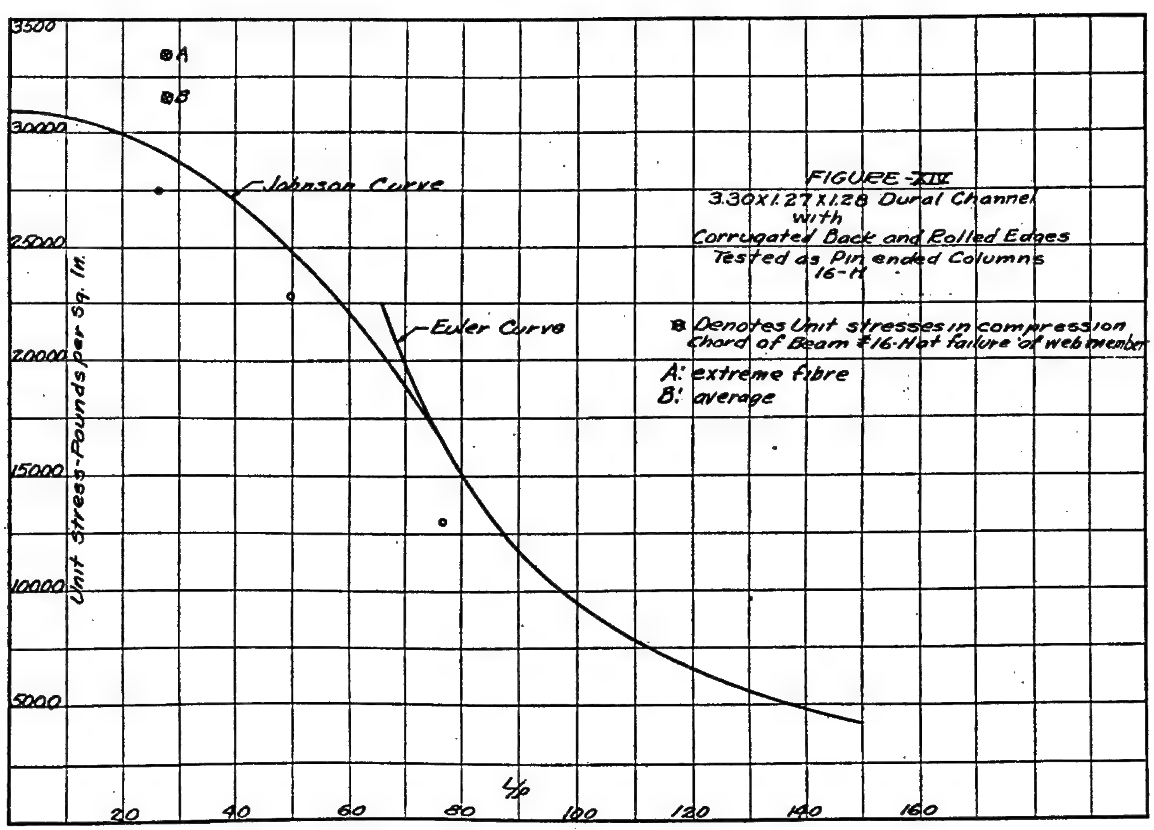

A
B
C
Johnson Curve
Euler Curve
FIGURE - XII
3 1/2 x 1/4 x .128 Dural Channels
Tested as pin ended columns
16-C
Denotes Unit Stresses in Compression Chord of Beam No.16C at failure
A: at extreme fibre
B: average
C: at free edge of sides or legs.
Unit Stress - Pounds per Sq. Inch
L/ρ
35000
30000
25000
20000
15000
10000
5000
20
40
60
80
100
120
140
160

FIG. 12



35000
30000
25000
20000
15000
10000
5000
Unit Stress - Pounds per Sq. Inch
A
B
C
Johnson Curve
Euler Curve
Denotes Unit Stresses in Compression Chord of Beam No.166 at failure
A: Extreme fibre
B: Average
C: At free edges of sides or legs.
L/ρ
20
40
60
80
100
120
140
160

FIG. 13



3500
30000
25000
20000
15000
10000
5000
Unit Stress-Pounds per Sq. In.
A
B
Johnson Curve
Euler Curve
FIGURE-XIV
3.30X1.27X1.28 Dural Channel with Corrugated Back and Rolled Edges Tested as Pin ended Columns 16-H
Denotes Unit stresses in compression Chord of Beam #16-H at failure of web member
A: extreme fibre
B: average
L/ρ
20
40
60
80
100
120
140
160

FIG. 14

where there is considerable variation in the value of the bending moment at different points, the section can be easily varied to obtain a very efficient and effective disposition of the material. The results of the tests of the specimens in this series are plotted in Figure 10.

The backs of the channels in the 16F and the 16G series were stiffened by forming a longitudinal corrugation in them. This method of stiffening the backs of channels is also effective, because it is attained at a small expense in weight and the material added to form the corrugation is also carrying its share of the load. It is not as advantageous for wing spars as that used in the 22B series, as it does not lend itself as readily to effecting changes in the moment of inertia of the spar. With thin gauge material, however, corrugations will effect a marked increase in strength with but little increase in the weight of the member. The results of the tests of the specimens in series 16F and 16G are plotted in Figures 11 and 13 respectively.

In the case of the channels in series 16H, the backs were stiffened by forming a longitudinal corrugation in them and the free edges were strengthened by turning them in. The effect of the corrugation in the back is the same as in series 16F and 16G. The effect of turning in or rolling the free edges of the sides is to strengthen them against local failure and at the same time to decrease the radius of gyration of the section. Therefore this method of stiffening should be most efficient in the thinner gauge materials with wide sides. It should also be noted that rolling the free edges makes it more difficult to rivet other members to the channel and results in a shape that is not as easily formed as are most other channel sections. The results of the tests of the specimens in this series are plotted in Figure 14.

The specimens in series 16–C are plain channels. The results of the tests are shown in Figure 12. Although the size of these specimens puts them outside the range of the investigation of plain channels and the gauge is much heavier than that used for the test specimens in the development of the design charts, the test results in this series agree very closely with the Johnson curve obtained from the design charts in Figures 8 and 9.

The computed stress intensities in these channels, as compression chords of the beams, at the loads at which the beams failed are also plotted in Figures 10 to 14, inclusive. The stress intensity at the outside fiber or back of the channel, the average stress intensity on the section and the unit stress at the free edges of the sides are shown in each case. In plotting these data the length used for the slenderness ratio is the distance between the panel points of the beam. A study of these data shows that the methods of stiffening employed have little or any effect on the ultimate strength of the strut except as they affect the radius of gyration of the section. When the stiffened section is used as the compression chord of a beam, however, a considerable increase in strength is obtained. This difference in the effect of the stiffening may be due to the difference in the stress distribution in the two cases. In the case of an axially loaded strut the stress intensity is uniform over the cross section, but when the channel is used as the compression chord of a beam with transverse bending loads the stress intensity varies from a maximum at the back of the channel to a minimum at the free edges. It should be noted that the back and side gauge ratios of these channel struts were relatively small and that the yield points for their Johnson curves were, in most cases, very nearly equal to the yield point of the material. It is reasonable to believe, then, that stiffening them would have little effect in increasing the yield points for their Johnson curves, but that these methods would be more effective when applied to channel struts with large back or side gauge ratios. It is believed that these methods of stiffening channel shapes, even in the case of channels of thin material and large dimensions, will have no effect in the Euler range except as the radius of gyration of the section is changed, but that their effect will be obtained as a correction factor to the yield point f in the Johnson curve for the plain unstiffened section.

In the case of a channel trussed beam submitted to the division for test, the free edges of the sides of of the channels forming the flanges of the beam were interconnected by means of bolts and tubular spacers. A study of the data submitted with the design and the test of the beam showed that though a strut can be stiffened somewhat by this means so as to have an increased ultimate strength, its strength weight ratio would be decreased except in cases where the side-gauge ratio of the channel is relatively large. Sufficient data are not at hand, so that the efficiency of this method of stiffening may be compared with that of the other methods used. It is not believed to be as effective, however, as the material added in obtaining the stiffening effect is not carrying any of the primary load.

The channels Nos. 1 to 18, inclusive, were stiffened by means of flanged lightening holes formed in the backs. Channels Nos. 15 and 16 were further stiffened by turning in the free edges about $\frac{3}{4}$ inch. The flanges of the lightening holes were approximately one-eighth inch in all cases except Nos. 13 to 16, inclusive, where the flanges were approximately one-fourth inch. The results of the tests in Table 4 show that the efficiency of the material was increased in some cases by this method of stiffening and decreased in others. The most favorable results were obtained in the channels with the larger side-gauge ratios and with the smaller lightening-hole spacing. These channels, however, had dimension ratios that placed them well outside the range of the tests on which the design charts were based. The assumption that the straight-line variation of the yield point holds for side-gauge ratios greater than 25 undoubtedly is conservative and contributes to the favorable showing for this method of stiffening. The test specimens are too few in number and too widely scattered to enable a rule for the effective use of this method of stiffening to be determined from the test data. It is believed, however, that this method will be found effective in thin-gauge channels of large dimensions.

Channel Trussed Beams.

A number of trussed channel beams were built and tested to failure during the course of this investigation.

The beams were tested over a 96-inch span by combined bending and compression loads, the transverse loads consisting of two concentrated loads applied at points 22.5 inches from the end supports. The jig in which these beams were tested is shown in Figures 2 and 3 and was so arranged that throughout the test each side load was equal to 10 per cent of the end load. The dimensions and properties of the beams and the flange channels are shown in Table 5; the physical properties and the loads at failure are shown in Table 6. The beams of the 16 series with the end fittings removed are shown in Figure 4. The tension and compression flanges were equal in each of the beams except Nos. 22B, 16D, and 16E. In some cases the chord channels were stiffened by plates or corrugations as shown in Figure 4 and Table 5. In beam No. 15A the sides of the chord channels were interconnected by bolts and tubular spacers. In all cases, except beam No. 15A, the web members were stiffened by means of flanged lightening holes.

In Table 6 the ultimate strength of the compression chords of the beams are compared with the computed stresses due to the loads under which the beam failed. The ultimate strength of the compression flange in each case was obtained from the design charts in Figures 8 and 9, the length used in computing the slenderness ratio being the distance between panel points and the fixity at the ends being assumed that of pin-ended columns. The stress intensity in the compression chords at the maximum load is computed by two methods. The values of the average unit stress are computed by the girder method formula: $f=\frac{P}{A}+\frac{M}{aA_o}$, where P is the axial load, M is the maximum bending moment which occurs at mid span, A_o is the area of the compression flange, A is the area of the two flanges, and a is the effective depth of the beam or the distance between the centroids of the flanges. The values of the maximum unit stress are computed by the ordinary beam formula: $f=\frac{P}{A}+\frac{Mc}{I}$, where P, M, and A have the same significance as in the previous formula, c is the distance from the neutral axis of the beam to the outside fiber of the compression flange and I is the moment of inertia of the areas of the flanges about their neutral axis. In both cases, the maximum bending moment at mid span is assumed equal to $Wd+PY$ where W is one of the two equal side loads, d is the distance from a point of support to the nearest side load, P is the axial load and Y is the measured deflection at mid span. In the case of beams 16 A, B, and C the three beams that had equal unstiffened chords, a comparison of the unit stresses at failure with the allowable unit stresses obtained from the design charts shows that the values computed by the girder method exceeded the allowable values by an average of 7 per cent and that the values computed by the ordinary beam formula exceeded the allowable values by an average of 12 per cent. It is believed that this difference is due in part, at least, to the fact that the actual stress intensity in the compression chords of the beams varies from a maximum at the back of the channel to a minimum at the free edges of the sides and that the fixity of the chords at the panel points is somewhat greater than that of pin-ended columns due to the action of the web members.

In the case of beam 15A the average stress intensity at the maximum load exceeded the allowable by 13.9 per cent. The compression chord of this beam was stiffened by interconnecting the sides of the channel by bolts and tubular spacers. In the case of beam 22B the compression chord was strengthened by means of a reenforcing strip riveted to the back of the channel, and in the case of beam 16F the flanges were strengthened by means of a corrugation formed in the backs of the channels. Both these methods are more effective than the method used in beam 15A as they stiffen the compression chord in the back, the highest stressed portion of the member. The average stress intensity at maximum load exceeded the allowable by 23.7 per cent in the case of beam 22B and by 19.9 per cent in the case of beam 16F.

A direct comparison of the merits of the methods of stiffening used in beams 22B and 16F can not be made as the tests of the minor parts of the two beams showed that the material in beam 22B had an ultimate strength 7.3 per cent greater than that in beam 16F. The flanges in beams 16G and 16H were stiffened by corrugations in the backs of the channels as in beam 16F and in addition the free edges of the sides of the chord channels of beam 16H were rolled in. The results of the tests of these two beams are not directly comparable with the allowable stress intensities from the design charts or with the results of the tests of the other beams as these two beams failed in the web members and riveted joints. In the case of beams 16D and 16E which were built with unequal chords, the results are of little value as the tests of the minor parts showed that the material in the flanges was of inferior quality.

As it was noted in early tests of the 96-inch metal beams that the measured deflection was generally greater than the computed deflections, the values of EI both about the minor or $x-x$ axis and about the major or $Y-Y$ axis of each beam were measured in cross bending before the beam was static tested to failure. These measurements were obtained by supporting the beam in a 25,000-pound Olsen testing machine and applying equal concentrated loads at the two points 22.5 inches from the end supports, the deflections under load being read by means of a surveyor's transit. The results of these measurements are given in Table 6. They show that the measured values of EI about the $Y-Y$ axis agree very closely with the computed values which are the product of the computed moments of inertia of the spar flanges and an assumed value of 10,000,000 pounds per square inch for the modulus of elasticity of the material. The measured values of EI about the $X-X$ axis are not in agreement with the computed values, however, the general average of the former being approximately 80 per cent of the latter. It is believed that this difference between the measured and computed values of EI about the $X-X$ axis is largely due to the effect of slip

in the riveted joints and to the effect of shear deflections, the latter probably having the greater effect as the span-depth ratio of the beams was only $\frac{96}{6.25}=15.36$. In the case of wing spars the span-depth ratios are generally much nearer to 30, the value commonly required by the Matériel Division in a small test beam for the purpose of obtaining Young's modulus for the material. It is probable, then, that, in the case of metal beams of this character for wing spars, the computed values of EI should be reduced somewhat for use in the precise formulas. It is recommended that the moment of inertia be computed for the area of the two flanges and that the modulus of elasticity be assumed equal to 9,000,000 pounds per square inch for the purpose of computing the effect of the axial loads on the moments and shears in wing spars until additional tests are conducted to clarify this phase of metal beam design.

In checking the results of the tests of the beams it was noted that in several cases the deflections were considerably greater at loads near the maximum than the computed values based on the use of the measured EI for the beam. The beams Nos. 16 B to H, inclusive, had similar web systems, as shown in Figure 4. In an effort to reduce the weight to a minimum, the joints between the web members and the chord channels were made with two rows of rivets instead of a single row as was used in beam 16A. As the beams 16G and H had failed in their web systems, the loads in the web system of beam 16G were checked. A study of the load deflection curve showed that the curve plotted from computed data, using the measured value of EI, agreed with the curve plotted from the deflection observed during the test until the end load reached 18,000 pounds. At this load the observed deflection at mid span was 0.61 inch and the computed deflection 0.64 inch. The average stress intensity in the compression chord in mid span computed by the girder method was approximately 27,000 pounds per square inch at this end load, a value somewhat below the yield point of the flange material. By means of the Newell precise formula the shear was computed in the beam at the middle of the first tension and first compression web members, the resulting values being 2,176 and 2,153 pounds respectively. Assuming that the loads in the shear members were direct functions of the computed shear, the axial loads in the two web members were +3024 pounds and −2988 pounds, respectively. The eccentricities in the joints were difficult to determine accurately, as it was not known what allowance to make for the flanged lightening holes in computing the location of the neutral axis of the members, but it was thought that a value of one-fourth inch was a reasonable one. The maximum bending moments in the web members then are 756 inch-pounds and 747 inch-pounds, respectively. In both cases the eccentricities were such that the maximum unit stress was at the free edge of the sides of the channels and was as follows, using the properties of the unlightened section.

Tension member:

$$f=\frac{3,024}{0.1398}+\frac{756\times0.695}{0.008931}=+80,462\#/\square''$$

Compression member:

$$f=-\frac{2,988}{0.231}-\frac{747\times0.694}{0.0148616}=-47,818\#/\square''$$

It is apparent that the approximations made in obtaining these stress intensities were conservative, but nevertheless the computations indicate that at this point the web members were highly stressed, probably beyond their yield points, and that for this reason the deflection of the beam increased very rapidly after this point for small increases in the external loads.

It will be noted in Table 6 that values of the allowable unit shear stress are shown for the radius of gyration of the compression flanges about the $Y-Y$ axis. In the beams with equal flanges these values prevail also for the whole beam section. With the exception of beams 16 D and E the computed stress at maximum load by the girder method is greater than the allowable unit stress about the $Y-Y$ axis. It seems certain, then, that the compression chords would have failed transversely as 48-inch columns, the distance between points of side support, if they had not been supported by the more lightly loaded tension flanges. The support of the tension flange can reach the compression flange only through the web system and the ability of the tension flange to aid the compression flange is a measure of the torsional strength and rigidity of the beam. The torsion action in the beam between the side supports was very noticeable during the tests as the unit stress in the compression flange reached the allowable unit stress about the $Y-Y$ axis.

It is believed that the design charts in Figures 8 and 9 may be used in the design of trussed-channel beams for the range covered by the tests on which they are based. Both the moments and shears should be computed by a precise method. The computed value of the moment of inertia of the flanges with the standard modulus of elasticity of the material reduced to 9,000,000 pounds per square inch may be used for the computations of the secondary bending moments and shears with satisfactory results, provided the stresses in the members used do not exceed the yield point of the material before the design load is approached. The stress intensity in the flanges should be computed by the girder method, as it is believed that the use of the ordinary beam formula would result in unnecessary weight if channels were then selected by means of the design charts in Figures 8 and 9.

In computing the allowable unit stress for a web or chord member, the length used for the slenderness ratio should be the distance between panel points. The fixity coefficient for use in the column formulas should be $C=1$ in the case of flanges and $C=2$ in the case of web members, provided the riveted joints are so designed as to be able to resist bending loads. The data resulting from these tests are not sufficient to clarify the question of the degree of restraint of the ends of the members of a beam

of the character tested. The beams listed in Table 6 were so designed that the values of the slenderness ratios of the compression chords were so small that differences assumed in the degree of the end restraint have relatively small effect on the allowable unit stresses. It seems certain that the bending strength of the web members and the joints between them and the flanges have considerable influence on the restraint of the flanges at the panel points. Until additional tests are conducted to clarify this phase of the design it is thought best to assume that the chord members are pin ended at their panel points.

The effect of stiffening the backs or sides of the channels used in trussed beams is not clearly defined by these data. It is apparent that the methods used in this investigation had little if any effect on the channels when loaded as struts. When the channels were used as the chords or flanges of beams, however, the effect of the stiffening was considerable, though the data are too little to enable a rule for their use to be formulated. These data show that care should be exercised in the design of a metal beam to provide sufficient transverse or torsional strength. The amount needed in a given case is not readily determined but apparently in a beam of the character covered in this report, as in a wood box beam, the requisite torsional strength is provided without special effort on the part of the designer. The tests of beams 16 D and E threw little light on the result of strengthening the highly stressed compression flange at the expense of the more ligthly loaded tension flange. Theoretically it is advantageous to do this, and additional tests should be conducted to clarify this point.

The riveted joints used in the beams in this investigation merit a great deal of care on the part of the designer. It is quite difficult at times to provide the necessary rivet space without undue increases in weight or without creating eccentricities that may prove serious on account of the relatively small moment of inertia that prevails as a rule in small channels. The design should always be checked to determine the effect of eccentricities, if any, on the strengths of the joints and the members concerned. The joints may be effected by lugs formed in the sides of the channels or by gusset plates. Neither of these forms are necessary, however, if the sides of the channels are wide enough to provide the necessary rivet space. In any case it should always be remembered that there is a secondary stress in the members due to deflection of the beam which tends to change the angularity of the members and for this reason the designer should not attempt to design too close or the riveted joints may actually have a negative margin of safety. No comprehensive rule for the allowance to be made to cover these secondary stresses can be justified by the meager data at hand. In the case of the beams of the 16 series shown in Tables 5 and 6 the riveted joints were so designed that their strength was approximately 25 per cent in excess of that required by the direct stresses. Regardless of the value of the direct stress, at least three rivets should be used at each lug or gusset plate. The riveted joints so designed were entirely satisfactory in beam 16A. With the remainder of the beams of the 16 series, eccentricities existing at the joints had a serious effect on their efficiency. The formulas for rivet spacing in steel are satisfactory for use in the design of riveted joints if the strength properties of duralumin specified by the Matériel Division are used.

Sheet duralumin can not with safety be bent to as sharp a radius as sheet steel of equivalent gauge. It is of great importance that the designer recognize this difference in the two materials and specify the appropriate radius when designing structural shapes of duralumin for use in airplanes. In the course of this investigation a number of thin gauge channels inadvertently were given too sharp a radius of bend during the forming operation. As a result fine longitudinal cracks were noticeable along the inner surface at the bends. These cracks did not affect the ultimate strength of the specimens when static tested but it is probable that they would have proved serious if the channels had been incorporated in an airplane on account of the repetition of stress and the vibration to be met with in structures of this type.

TABLE 1.—*Duralumin channels tested as pin-ended columns*

Test specimen No.	Length	Size				Size in terms of the gauge t	Area	Least I	$\frac{L}{\rho}$	Properties of the material		Column load at failure	Unit stress at failure
		Side	Side	Back	Gauge					Yield point	Ultimate strength		
	Inches												
47	5.90	1.25	1.25	2.53	0.050	50.6×25.0	0.2427	0.03809	14.90			3,750	15,450
48	5.90	1.25	1.25	2.53	.050	50.6×25.0	.2427	.03809	14.90			3,100	12,770
49	9.90	1.25	1.25	2.50	.051	49.0×24.5	.2459	.03866	24.97			3,500	14,230
50	9.90	1.25	1.25	2.50	.051	49.0×24.5	.2459	.03866	24.97			2,900	11,790
51	13.95	1.25	1.25	2.50	.050	50.0×25.0	.2412	.03794	35.18			4,510	18,700
52	13.95	1.25	1.25	2.50	.050	50.0×25.0	.2412	.03794	35.18			3,500	14,510
53	17.84	1.25	1.25	2.50	.051	49.0×24.5	.2459	.03866	45.00			3,070	12,480
54	17.84	1.25	1.25	2.50	.051	49.0×24.5	.2459	.03866	45.00			3,010	12,240
55	21.80	1.25	1.25	2.50	.051	49.0×24.5	.2459	.03866	55.00			2,860	11,630
56	21.80	1.25	1.25	2.50	.051	49.0×24.5	.2459	.03866	55.00			3,080	12,530
57	25.78	1.25	1.25	2.50	.051	49.0×24.5	.2459	.03866	65.10			2,730	11,100
58	25.78	1.25	1.25	2.50	.051	49.0×24.5	.2459	.03866	65.10			2,700	10,980
59	29.73	1.25	1.25	2.50	.054	46.3×23.15	.2600	.04077	75.00			2,510	9,650
60	29.73	1.25	1.25	2.50	.054	46.3×23.15	.2600	.04077	75.00			2,650	10,190
61	33.65	1.25	1.25	2.50	.050	50.0×25.0	.2412	.03794	84.85			2,150	8,910
62	33.65	1.25	1.25	2.50	.050	50.0×25.0	.2412	.03794	84.85			2,050	8,500
63	37.69	1.25	1.25	2.50	.050	50.0×25.0	.2412	.03794	95.00			2,560	10,610
64	37.69	1.25	1.25	2.50	.050	50.0×25.0	.2412	.03794	95.00			2,000	8,290
65	14.28	1.25	1.25	1.25	.052	24.0×24.0	.1856	.03086	35.00	37,270	61,650	3,130	16,860
66	14.28	1.25	1.25	1.25	.052	24.0×24.0	.1856	.03086	35.00	36,780	61,350	2,780	14,980
67	14.27	1.25	1.25	1.50	.051	29.4×24.5	.1949	.03242	35.00			2,420	12,420
68	14.27	1.25	1.25	1.50	.051	29.4×24.5	.1949	.03242	35.00			2,970	15,240
69	14.13	1.25	1.25	2.00	.052	38.5×24.0	.2246	.03655	35.06			3,450	15,360
70	14.13	1.25	1.25	2.00	.052	38.5×24.0	.2246	.03655	35.06			2,700	12,020
51	13.95	1.25	1.25	2.50	.050	50.0×25.0	.2412	.03794	35.18			4,510	18,700
52	13.95	1.25	1.25	2.50	.050	50.0×25.0	.2412	.03794	35.18			3,500	14,510
71	13.60	1.25	1.25	3.00	.051	58.8×24.5	.2714	.04090	35.00			3,750	13,820
72	13.60	1.25	1.25	3.00	.051	58.8×24.5	.2714	.04090	35.00			3,600	13,260
73	13.30	1.25	1.25	3.50	.051	68.6×24.5	.2969	.04270	35.06			3,350	11,280
74	13.30	1.25	1.25	3.50	.051	68.6×24.5	.2969	.04270	35.06			3,750	12,630
75	18.20	1.62	1.62	1.60	.062	25.8×26.1	.2808	.07818	34.50			4,130	14,710
76	18.20	1.62	1.62	1.60	.062	25.8×26.1	.2808	.07818	34.50			3,800	13,530
77	18.25	1.60	1.60	1.95	.064	30.5×25.0	.3093	.08411	34.96			3,800	12,290
78	18.25	1.60	1.60	1.95	.064	30.5×25.0	.3093	.08411	34.96			4,370	14,130
79	18.08	1.60	1.60	2.56	.063	40.6×25.4	.3431	.09178	34.90	39,800	58,000	3,500	10,200
80	18.08	1.60	1.60	2.56	.063	40.6×25.4	.3431	.09178	34.90			3,550	10,350
81	17.80	1.62	1.62	3.25	.063	51.6×25.7	.3891	.10317	34.56			4,250	10,920
82	17.80	1.62	1.62	3.25	.063	51.6×25.7	.3891	.10317	34.56			3,850	9,900
83	17.43	1.61	1.61	3.90	.063	61.9×25.6	.4288	.10734	34.80			5,160	12,030
84	17.43	1.61	1.61	3.90	.063	61.9×25.6	.4288	.10734	34.80			5,110	11,920
85	17.05	1.62	1.62	4.50	.063	71.4×25.7	.4678	.11419	34.50			5,060	10,820
83	17.05	1.62	1.62	4.50	.063	71.4×25.7	.4678	.11419	34.50			5,400	11,540

TABLE 2.—*Duralumin Channels Tested as Pin-ended Columns*

Test specimen No.	Length	Size				Size in terms of the gauge t	Area	Least I	$\frac{L}{\rho}$	Properties of the material		Column load at failure	Unit stress at failure	Point of failure
		Side	Side	Back	Gauge					Yield point	Ultimate strength			
	Inches													
15	4.08	0.84	0.85	1.75	0.053	33.0×16.0	0.1767	0.01227	15.47			5,000	28,300	Leg.
16	4.08	.94	.96	1.75	.053	33.0×18.1	.1878	.01700	13.55			4,570	24,330	Do.
27a	4.15	.91	.94	1.75	.051	34.3×18.4	.1784	.01523	14.19			4,130	23,150	Do.
28a	4.15	.96	.96	1.75	.052	33.7×18.4	.1854	.01718	13.62			3,380	18,230	Do.
30a	4.17	.92	.93	1.74	.051	34.1×18.2	.1778	.01520	14.25			3,520	19,800	Do.
17	6.90	.88	.91	1.72	.052	33.1×17.5	.1771	.01408	24.46			4,335	24,480	Do.
18	6.90	.83	.90	1.72	.052	33.1×17.3	.1740	.01281	25.45			3,630	20,860	Do.
19	9.60	.97	.98	1.73	.054	32.0×18.1	.1928	.01850	31.00			4,170	21,630	Do.
20	9.60	.93	.94	1.75	.053	33.0×17.7	.1862	.01627	32.45			4,330	23,250	Do.
21	12.37	.96	.96	1.77	.052	34.0×18.4	.1864	.01725	40.60			4,250	22,800	Do.
22	12.37	.96	.97	1.78	.052	34.2×18.6	.1875	.01753	40.40			4,080	21,760	Do.
23	15.13	.95	.98	1.74	.052	33.5×18.8	.1854	.01740	49.40			3,140	16,940	Do.
24	15.15	.97	1.04	1.72	.052	33.1×20.0	.1885	.01939	47.20	37,450	58,900	4,140	21,960	Do.
25	17.95	.90	1.00	1.76	.051	34.5×19.6	.1814	.01643	59.65	37,670	60,800	3,350	18,470	Do.
26	17.95	.92	.95	1.76	.052	33.9×18.3	.1833	.01600	60.70	36,680	58,300	3,210	17,510	Do.
28	20.65	.96	.96	1.75	.052	33.7×18.4	.1854	.01718	67.80	34,880	55,800	3,220	17,370	Back.
27	20.68	.91	.94	1.75	.051	34.3×18.4	.1784	.01523	70.20	36,520	56,690	2,940	16,480	Leg.
29	23.45	.92	.93	1.75	.052	33.7×17.9	.1818	.01551	80.20			2,620	14,410	Back.
30	23.45	.92	.93	1.74	.051	34.1×18.2	.1778	.01520	80.20	31,530	52,700	2,520	14,170	Do.
37	9.90	.87	.89	1.00	.053	18.9×16.8	.1406	.01140	34.74			2,840	20,200	Leg.
38	9.86	.86	.86	1.03	.053	19.4×16.2	.1401	.01081	35.44			3,280	23,410	Do.
19	9.60	.97	.98	1.73	.054	32.0×18.1	.1928	.01850	31.00			4,170	21,630	Do.
20	9.60	.93	.94	1.75	.053	33.0×17.7	.1862	.01627	32.45			4,330	23,250	Do.
39	9.08	.88	.90	2.48	.052	47.7×17.3	.2161	.01542	34.00			4,120	19,070	Do.
40	9.12	.87	.88	2.50	.052	48.1×16.9	.2156	.01474	34.85			4,520	20,960	Do.
42	8.37	.82	.83	3.48	.052	67.0×16.0	.2613	.01351	36.78			3,400	13,010	Do.
41	8.36	.85	.86	3.50	.052	67.3×16.5	.2655	.01499	35.15			2,680	10,090	Do.

TABLE 3.—*Duralumin channels tested as pin-ended columns*

Test specimen No.	Length	Size				Size in terms of the gauge t	Area	Least I	$\frac{L}{\rho}$	Column load at failure	Unit stress at failure	Point of failure
		Side	Side	Back	Gauge							
	Inches											
2x	2.80	0.65	0.70	1.26	0.053	23.8×13.2	0.1327	0.00592	13.27	4,200	31,650	Back.
1x	2.86	.64	.65	1.26	.053	23.8×12.2	.1295	.00521	14.26	4,250	32,820	Do.
11b	4.00	.71	.74	1.26	.052	24.2×14.2	.1355	.00710	17.46	3,830	28,270	Leg.
12a	4.00	.70	.72	1.27	.052	24.4×13.8	.1344	.00672	17.90	4,140	30,800	Do.
11a	4.02	.71	.74	1.26	.052	24.2×14.2	.1355	.00710	17.54	3,220	23,760	Do.
12b	4.04	.70	.72	1.27	.052	24.4×13.8	.1344	.00672	18.08	3,820	28,420	Do.
4	4.85	.70	.74	1.20	.052	23.1×14.2	.1318	.00686	21.26	3,860	29,290	Back.
3	4.87	.70	.75	1.20	.052	23.1×14.4	.1324	.00699	21.20	3,860	29,150	Do.
10a	6.30	.72	.73	1.26	.052	24.2×14.0	.1355	.00710	27.50	3,860	28,490	Do.
5	6.77	.70	.72	1.26	.052	24.2×13.8	.1339	.00670	30.25	4,015	29,990	Do.
6	6.83	.69	.71	1.27	.052	24.4×13.8	.1334	.00647	31.00	3,850	28,860	Do.
14a	8.00	.70	.72	1.27	.052	24.4×13.8	.1344	.00672	35.80	3,700	27,530	Leg.
7	8.61	.72	.75	1.25	.052	24.0×14.4	.1360	.00736	37.00	3,515	25,850	Back.
8	8.81	.70	.72	1.26	.052	24.2×13.8	.1339	.00670	39.40	3,220	24,050	Do.
9	10.62	.72	.75	1.27	.052	24.4×14.4	.1370	.00740	45.70	3,250	23,720	Do.
10	10.65	.72	.73	1.26	.052	24.2×14.0	.1355	.00710	46.50	3,520	25,980	Do.
12	12.73	.70	.72	1.27	.052	24.4×13.8	.1344	.00672	57.00	2,920	21,730	Do.
11	12.75	.71	.74	1.26	.052	24.2×14.2	.1355	.00710	55.70	3,110	22,950	Do.
14	14.62	.70	.72	1.27	.052	24.4×13.8	.1344	.00672	65.40	2,410	17,930	Leg.
13	14.63	.70	.72	1.26	.052	24.2×13.8	.1339	.00670	65.40	2,600	19,420	Back.
31	6.97	.63	.64	0.99	.053	18.7×12.1	.1141	.00461	34.65	3,320	29,100	Leg.
32	6.95	.63	.63	1.01	.053	19.1×11.9	.1146	.00454	35.00	3,110	27,140	Do.
10a	6.30	.72	.73	1.26	.052	24.2×14.0	.1355	.00710	27.50	3,860	28,490	Back.
5	6.77	.70	.72	1.26	.052	24.2×13.8	.1339	.00670	30.25	4,015	29,990	Do.
6	6.83	.69	.71	1.27	.052	24.4×13.8	.1334	.00647	31.00	3,850	28,860	Do.
33	6.07	.71	.72	2.48	.052	47.7×13.8	.1979	.00830	29.60	4,270	21,580	Leg.
34	6.08	.70	.71	2.48	.052	47.7×13.6	.1968	.00797	29.65	4,200	21,340	Do.
35	5.54	.69	.70	3.48	.053	65.7×13.2	.2524	.00838	30.40	3,470	13,750	Do.
36	5.55	.69	.70	3.43	.053	65.7×13.2	.2524	.00838	30.45	5,470	21,670	Do.
43	5.55	.60	.60	3.50	.051	68.7×11.8	.2345	.00528	37.00	3,980	16,970	Back.
44	5.50	.60	.60	3.50	.051	68.7×11.8	.2345	.00528	36.65	4,200	17,910	Do.
46	5.49	.60	.60	3.50	.051	68.7×11.8	.2345	.00528	36.60	4,080	17,400	Leg.
45	5.55	.60	.60	3.52	.051	69.0×11.8	.2355	.00529	37.00	4,000	16,990	Do.

TABLE 4.—*Duralumin channels tested as pin-ended columns*

Article No.	Size	Type or method of stiffening	Area	Least I	Least ρ	L	L/ρ	End load at failure	Unit stress at failure	Yield point for P/A at failure	Plain channel of same dimensions: Yield point	Plain channel of same dimensions: Computed end load	Ratio: End load to volume: Test article	Ratio: End load to volume: Similar plain channel
22B-1	3.00 ×1.145×0.125	0.9×0.125 dural piece, riveted to back	0.5965	0.06957	0.3415	10.35	30.31	20,800	29,340	31,750	32,067	17,661	2,793	2,861
22B-2	3.02 ×1.110× .125	do	.5902	.06383	.3288	15.30	46.5	11,600	16,510	18,420	31,930	15,453	1,064	1,711
22B-3	3.03 ×1.110× .125	do	.5915	.06390	.3287	20.27	61.7	11,140	15,825	19,650	31,894	12,908	770	1,077
16F-1	3.54 × .865× .123	Corrugation in back, 0.25-inch radius	.5962	.03070	.2268	7.61	33.55	15,850	26,580	29,050	27,350	14,707	3,493	3,306
16F-2	3.54 × .885× .124	do	.6061	.03326	.2343	10.26	43.8	15,340	25,310	29,720	27,703	14,184	2,467	2,327
16F-3	3.535× .885× .125	do	.6106	.03319	.2330	12.38	53.1	12,450	20,390	24,960	27,754	13,223	1,647	1,785
16F-4	3.535× .89 × .125	do	.6118	.03374	.2348	17.75	75.6	8,910	14,560	21,300	27,826	9,777	820	919
16F-5	3.53 × .875× .124	do	.6027	.03212	.2308	23.87	103.4	5,250	8,710		27,595	5,615	365	398
16C-1	3.295×1.265× .129	None	.6833	.09810	.3789	9.53	25.15	19,550	28,610	30,100	31,322	20,300	3,002	3,117
16C-2	3.296×1.27 × .128	do	.6797	.09049	.3649	17.96	49.2	17,890	26,320	33,300	31,228	17,047	1,465	1,396
16C-3	3.296×1.28 × .127	do	.6773	.09281	.3702	28.25	76.3	10,350	15,280	24,000	31,075	11,135	541	582
16G-1	3.30 ×1.265× .126	Corrugation in back, 0.25-inch radius	.6815	.09247	.3684	9.60	26.06	20,150	29,570	31,300	31,034	19,622	3,080	3,055
16G-2	3.30 ×1.26 × .124	do	.6696	.09029	.3672	18.00	49.0	19,000	28,370	36,870	30,810	16,362	1,576	1,382
16G-3	3.31 ×1.255× .126	do	.6802	.09047	.3646	27.95	76.65	10,630	15,630	25,850	30,962	10,884	559	583
16H-1	3.30 ×1.27 × .128	Corrugation in back, rolled edges, 0.25-inch radius	.6928	.09405	.3684	9.63	26.14	19,000	27,425	28,910	30,935	19,860	2,848	3,037
16H-2	3.30 ×1.27 × .128	do	.6928	.09405	.3684	18.24	49.5	15,800	22,806	27,700	30,935	16,888	1,250	1,363
16H-3	3.30 ×1.27 × .128	do	.6928	.09405	.3684	28.32	76.9	9,000	12,990	17,950	30,935	11,081	459	576
11	2.58 × .67 × .038	0.804-inch flanged holes 1.204-inches, center to center	.1461	.005228	.1892	8.22	43.45	1,128	7,722 9,765	8,040	17,505	2,338	1,010	1,947
12	2.59 × .67 × .038	do	.1465	.005233	.1890	8.14	43.1	1,136	7,757 9,800	8,070	17,458	2,342	1,025	1,964
7	3.05 × .61 × .031	1.588-inch flanged holes 2.188 inches, center to center	.1304	.003431	.1621	8.31	51.25	888	6,807 10,930	7,160	12,228	1,461	939	1,348
8	2.99 × .62 × .031	do	.1292	.003581	.1663	8.32	50.0	934	7,230 11,680	7,610	12,432	1,476	997	1,373
3	3.24 × .61 × .031	1.738-inch flanged holes 2.238 inches, center to center	.1363	.003471	.1596	8.30	52.0	854	6,264 10,360	6,570	11,392	1,428	883	1,262
4	3.24 × .62 × .031	do	.1370	.003638	.1629	8.29	50.9	858	6,265 10,330	6,550	11,356	1,437	883	1,265
9	2.57 × .875× .031	0.818-inch flanged holes 1.218 inches, center to center	.1320	.009158	.2634	8.06	30.6	1,292	9,788 12,120	10,030	7,500	972	1,298	914
10	2.56 × .87 × .031	do	.1314	.009004	.2618	8.05	30.74	1,247	9,492 11,760	9,730	7,690	992	1,260	938
5	2.99 × .865× .030	1.59-inch flanged holes 2.19 inches, center to center	.1398	.008931	.2527	8.22	32.53	1,337	9,564 14,520	9,830	6,240	857	1,317	740
6	3.00 × .86 × .030	do	.1398	.008794	.2506	8.53	34.04	1,373	9,820 14,910	10,130	6,320	866	1,297	726
1	3.24 × .89 × .032	1.736-inch flanged holes 2.236 inches, center to center	.1586	.01049	.2572	8.47	32.95	1,209	7,625 11,720	7,800	7,124	1,107	1,030	824
2	3.26 × .88 × .032	do	.1586	.01017	.2532	8.24	32.54	1,342	8,470 13,020	8,680	7,373	1,146	1,180	877
17	2.97 × .875× .050	1.55-inch flanged holes 2.20 inches, center to center	.2310	.01486	.2536	8.40	33.12	3,180	13,766 20,717	14,350	19,035	4,158	1,851	2,143
18	2.97 × .875× .050	do	.2310	.01486	.2536	8.32	32.80	2,738	11,853 17,837	12,280	19,035	4,163	1,611	2,166
13	2.69 ×1.20 × .050	1.55-inch flanged holes 3 inches, center to center	.2495	.03502	.3746	7.26	19.38	2,679	10,740 15,576	10,860	13,925	3,427	1,611	1,892
14	2.70 ×1.19 × .050	do	.2490	.03426	.3709	7.23	19.50	2,799	11,240 16,320	11,360	14,134	3,470	1,695	1,927
15	2.69 ×1.195× .050	1.50-inch flanged holes, 3.1 inches, center to center, edges turned in 0.425 inch.	.2865	.05931	.455	7.32	16.10	4,920	17,173 23,262	17,380	14,044	3,448	2,492	1,892
16	2.70 ×1.205× .050	do	.2885	.06086	.4593	7.32	15.94	5,345	18,527 25,035	18,760	13,791	3,408	2,722	1,859

NOTE.—These specimens were salvaged from the beams shown in Tables 5 and 6.

TABLE 5.—*Cross section properties trussed channel beams*

Beam No.	Beam						Compression flange						Tension flange					
	Size	Area	I_{x-x}	I_{y-y}	Effective depth	Y	Size	Area	I_{x-x}	ρ_{x-x}	I_{y-y}	ρ_{y-y}	Size	Area	I_{x-x}	ρ_{x-x}	I_{y-y}	ρ_{y-y}
15-A	6.62×2.12	1.1600	9.206	0.854	5.552	3.312	2.125×1.50×0.131	0.580	0.1069	0.4290	0.4270	0.858	2.125×1.50×0.131	0.580	0.1069	0.4290	0.4270	0.858
22-B	6.25×3.05	1.2190	10.011	1.381	5.730	2.854	[1] 3.05 ×1.00× .125	.666	.0470	.2658	.6942	1.021	3.05 ×1.00× .125	.553	.0463	.2802	.6866	1.114
16-A	6.25×3.06	1.261	9.933	1.657	5.562	3.125	3.06 ×1.25× .125	.630	.0901	.3780	.8285	1.046	3.06 ×1.25× .125	.630	.0901	.3780	.8285	1.046
16-B	6.30×3.30	1.247	10.274	1.834	5.701	3.150	3.30 ×1.16× .122	.623	.0731	.3422	.9172	1.212	3.30 ×1.16× .122	.623	.0731	.3422	.9172	1.212
16-C	6.31×3.30	1.350	10.902	2.039	5.631	3.155	3.30 ×1.27× .127	.675	.0980	.3810	1.0194	1.228	3.30 ×1.27× .127	.675	.0980	.3810	1.0194	1.228
16-D	6.30×2.91	1.173	8.755	1.340	5.577	2.487	2.91 ×1.24× .156	.728	.1011	.3726	.8268	1.066	2.79 ×1.27× .090	.445	.0691	.3940	.5134	1.074
16-E	6.26×2.92	1.166	8.233	1.335	5.576	2.291	2.92 ×1.39× .156	.776	.1404	.4255	.9233	1.090	2.76 ×1.00× .089	.389	.0347	.2985	.4113	1.028
16-F	6.28×3.56	1.188	10.208	1.793	5.845	3.140	[2] 3.56 × .88× .121	.594	.0314	.2300	.8968	1.228	3.56 × .88× .121	.594	.0314	.2300	.8968	1.228
16-G	6.29×3.30	1.355	10.770	2.011	5.590	3.145	[2] 3.30 ×1.27× .125	.677	.0927	.3700	1.0056	1.218	3.30 ×1.27× .125	.677	.0927	.3700	1.0056	1.218
16-H	6.29×3.30	1.386	11.034	2.100	5.595	3.145	[2] 3.30 ×1.27× .128	.693	.0940	.3684	1.0500	1.231	3.30 ×1.27× .128	.693	.0940	.3684	1.0500	1.231

[1] Has stiffening plate 0.90×0.125.
[2] Both flanges have a groove or corrugation in the back; 16-H also has the free edges rolled inwards.

TABLE 6.—*Physical properties trussed channel beams*

Beam No.	Ultimate strength of compression flange from design charts, Figures 8 and 9, $C=1$, $L=10.25$ inches						Ultimate strength of compression flange about $Y-Y$ axis $C=1$, $L=48$ inches		Loads at failure: Beam loads			Loads at failure: Chord stresses		Physical properties of flange material		Bending modulus about $X-X$ axis			Bending modulus about $Y-Y$ axis		
	Back side ratio	Yield point ratio	Yield point for standard channel	Yield point, corrected	L/ρ	P/A	L/ρ	P/A	Axial load	Deflection at mid-span	Maximum moment	Average unit stress	Maximum unit stress	Ultimate strength tension	Yield point tension	Computed EI	Measured EI	Ratio measured to computed EI	Computed EI	Measured EI	Ratio measured to computed EI
15-A	1.417	1.078	31,831	34,314	[1] 29.4	31,665	55.9	24,736	19,290	1.00	62,690	36,070	39,190	59,900	33,920	92,060,000	81,100,000	0.881	8,540,000	8,460,000	0.991
22-B	3.050	.860	36,540	31,424	[1] 24.0	29,940	47.0	25,746	19,800	1.75	79,200	37,015	38,830	59,400	--------	100,110,000	82,900,000	.828	13,807,000	13,080,000	.947
16-A	2.450	.940	33,769	31,743	27.1	29,820	45.9	26,217	18,500	.95	59,200	31,550	33,300	54,550	31,810	99,330,000	77,500,000	.781	16,570,000	16,920,000	1.021
16-B	2,845	.888	34,461	30,601	30.0	28,410	39.6	26,778	18,050	1.05	59,565	31,240	32,740	55,800	--------	102,740,000	83,700,000	.815	18,344,000	18,480,000	1.007
16-C	2.598	.920	33,769	31,067	26.9	29,250	39.1	27,226	18,750	1.10	62,812	30,400	32,070	54,200	--------	109,020,000	87,100,000	.799	20,388,000	20,700,000	1.015
16-D	2.347	.954	36,607	34,923	27.5	32,520	45.0	28,494	14,800	1.60	56,980	26,650	28,803	44,840	--------	87,550,000	79,900,000	.913	13,402,000	13,130,000	.980
16-E	2.100	.987	35,292	34,833	24.1	33,000	44.0	28,718	14,900	1.50	55,875	25,690	28,330	42,850	--------	82,330,000	72,300,000	.878	13,346,000	13,620,000	1.021
16-F	4.045	.727	37,550	27,300	44.6	23,440	39.1	24,334	16,740	.66	48,713	28,120	29,080	55,350	--------	102,080,000	78,000,000	.764	17,935,000	18,350,000	1.023
16-G	2.598	.920	33,561	30,876	27.7	28,970	39.4	27,023	20,150	1.25	70,525	33,500	35,460	58,550	--------	107,700,000	84,600,000	.786	20,112,000	20,200,000	1.004
16-H	2.598	.920	33,907	31,194	27.8	29,240	39.0	27,341	19,900	1.10	66,665	31,560	33,360	58,100	--------	110,340,000	87,400,000	.792	21,000,000	19,530,000	.930

[1] $L=12.625$ inches for Beam 15-A and 6.375 inches for 22-B.